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TECHNICAL REPORT
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REPLACEMENT SOLVENT IDENTIFICATION FOR THE LAUNDRY AND DECONTAMINATION DRYCLEANING SYSTEM (LADDS)

by
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A comprehensive industry search was carried out for the U.S. Army Natick Research, Development and Engineering Center (Natick) to identify potential solvent alternatives for use in present prototypes and future versions of Natick Laundry and Decontamination Drycleaning System (LADDS). The present LADDS prototype used 1,1,2-trichloro-1,2,2-trifluoroethane, a chlorofluorocarbon compound known as CFC-113, as the drycleaning solvent. However, CFC-113 has been identified as a ozone-depleting compound and its production and use are scheduled for phaseout under U.S. and international regulations to protect the stratospheric ozone layer. Consequently, Natick needs to identify alternative solvents available for use in the LADDS as well as to understand the engineering design changes that may be necessary in order to use the types of solvents that will be available for future LADDS.

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PREFACE

The purpose of this study was to document current efforts throughout industry and the military to develop CFC-113 replacements and to identify potential alternative solvents for use in the U.S. Army's Laundry and Decontamination Drycleaning System (LADDS).

The sponsor of this effort is the Aero-Mechanical Engineering Directorate (AMED) of the U.S. Army Natick Research, Development and Engineering Center (Natick). The authors wish to acknowledge Mr. Robert C. Hobbs, the program manager, and Mr. James McLaughlin of AMED for their technical guidance throughout this effort. The effort was initiated in October 1991 and completed in March 1992.

ABBREVIATIONS

ACGIH	American Conference of Governmental Industrial Hygienists
AFEAS	Alternative Fluorocarbons Environmental Acceptability Study
ANPR	Advance Notice of Proposed Rulemaking
ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
CAA	Clean Air Act (United States)
CAS	Chemical Abstract Registry Service
CBIAC	Chemical-Biological Information Analysis Center (U.S. Army CRDEC)
CFC	Chlorofluorocarbon
CRDEC	U.S. Army Chemical Research, Development, and Engineering Center
DIPPR-AIChE	Design Institute for Physical Property Data of the American Institute of Chemical Engineers
EC	European Community
EPA	Environmental Protection Agency (United States)
EPRI	Electric Power Research Institute (United States)
GWP	Global warming potential
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
IARC	International Agency for Research on Cancer
ICOLP	International Cooperative for Ozone Layer Protection
IDRC	International Drycleaning Research Committee
IFI	International Fabricare Institute
LADDS	Laundry and Decontamination Drycleaning System
MITI	Ministry of International Trade and Industry (Japan)
NAEDS	Non-Aqueous Equipment Decontamination System (U.S. Army CRDEC)
Natick	U.S. Army Natick Research, Development and Engineering Center
NBC	Nuclear, biological and/or chemical agent
NESHAP	National Emissions Standards for Hazardous Air Pollutants
ODP	Ozone depletion potential
OSHA	Occupational Safety and Health Administration
PEL	Permissible exposure limit
ppm	parts per million
SNAP	Significant New Alternatives Policy (U.S. EPA)
UNEP	United Nations Environmental Program

SECTION 1

SUMMARY

1.1 INTRODUCTION

A comprehensive industry search was carried out for the U.S. Army Natick Research, Development and Engineering Center (Natick) to identify potential solvent alternatives for use in present prototypes and future versions of Natick's Laundry and Decontamination Drycleaning System (LADDS). The present LADDS prototype uses 1,1,2-trichloro-1,2,2-trifluoroethane, a chlorofluorocarbon compound known as CFC-113, as the drycleaning solvent. CFC-113, however, has been identified as an ozone-depleting compound and its production and use are scheduled for phaseout under U.S. and international regulations to protect the stratospheric ozone layer. Consequently, Natick needs to identify alternative solvents available for use in the LADDS as well as to understand the engineering design changes that may be necessary in order to use the types of solvents that will be available for future LADDS. This six-month task was undertaken during the period from October 1991 through March 1992.

1.2 APPROACH

This task was undertaken to document current efforts to develop CFC-113 replacements and to identify alternative solvents that may be used effectively in the LADDS. Our approach began with literature data base searches followed by information gathering from industrial and government sources through telephone interviews. Over 75 information sources were contacted, both domestic and foreign, with an emphasis on sources in North America, Europe, and Japan. The information on various CFC-113 solvent replacements or alternatives was compiled and assessed regarding the potential for successful use as a LADDS solvent relative to criteria defined by Natick.

The technical and commercial directions for CFC-113 replacement activities are strongly influenced by the uncertainty of proposed amendments to regulations and international agreements defining the control of ozone-depleting compounds, as well as compounds suspected of contributing to global warming. This uncertainty influences the amount and depth of the information being released by industry regarding research and development activities. Most industrial enterprises were reluctant to reveal their long- and short-term strategies. We also found that the plans of several chemical producers changed, sometimes dramatically, over the course of this task in response to changes in phaseout schedules and regulations announced during this timeframe. Consequently, the information contained in this report reflects CFC-113 replacement activities as of February 1992, which may become less relevant as additional regulatory changes are promulgated. Thus, in our analysis of the potential CFC-113 solvent replacements, we attempted to consider the long-term feasibility and acceptability of the various alternatives.

1.3 CONCLUSIONS AND RECOMMENDATIONS

Many solvents and solvent mixtures are being pursued by industry as CFC-113 replacements. These include alcohols; aqueous cleaning systems; chlorinated solvents including dichloroethane, perchloroethylene, and trichloroethylene; hydrocarbons; hydrochlorofluorocarbons (HCFCs); hydrofluorocarbons (HFCs); perfluorocarbons (FCs); other fluorinated compounds including fluorinated alcohols, ethers, and morpholines; semi-aqueous or hydrocarbon/surfactant systems including glycol ethers, glycol ether acetates, esters, pyrollidone, and terpenes; and azeotropic and non-azeotropic mixtures. Most CFC-113 replacement efforts are targeted toward solvent cleaning of metal or electronic parts with little emphasis on drycleaning applications.

Relevant to LADDS solvent requirements:

- HCFCs under development appear to most closely meet the specified Natick solvent requirements, although HCFCs can only be regarded as a temporary solutions because of their own phase-out schedule.

- For traditional commercial drycleaning applications, perchloroethylene or high-boiling hydrocarbons are considered the best commercially available alternatives, with HCFCs considered as potential interim alternatives. Perchloroethylene or high-boiling hydrocarbons, however, do not meet the Natick requirement for a low boiling, low heat of vaporization solvent.

- Other solvents either commercially available or under development meet many of the Natick requirements for physical properties but are often deficient relative to flammability requirements. Also, the effects of these solvents on various materials, including fabrics and finishes, are not well documented.

- Several technical approaches and/or equipment are being pursued to improve suitability of some flammable or potentially toxic solvents, through the use of inert headspace gases or better control of solvent emissions.

As this effort neared completion, the acceptability of using HCFCs as interim substitutes for CFC-113 was placed in doubt. Because of regulations and uncertainties regarding toxicity, HCFCs will most likely not be available in commercial quantities in the U.S. Other fluorinated compounds, such as hydrofluorocarbons, fluorinated alcohols, and fluorinated ethers, may hold some promise as LADDS solvent alternatives in the future. However, there is only limited performance data and commercial availability of these compounds at present. Perchloroethylene may be a suitable alternative although the energy requirements for the LADDS will be higher because of its higher boiling point and heat of vaporization. Aqueous-based alternatives are being widely adopted a CFC-113 alternatives for many industrial solvent cleaning processes and are viewed by many as the most feasible, long-term, cost-effective alternative now available. The feasibility of using an aqueous cleaning system for future LADDS should be explored.

Solvent mixtures also offer advantages over single fluid approaches since mixtures can be used to reduce the toxicity, flammability, or solvating strength of one component by reducing its level in the mixture. Other benefits could include reduced energy costs and handling problems. Most of the solvent mixtures being examined commercially are limited to azeotropes to avoid the necessity for batch distillation systems and the complexities associated with concentration monitoring and makeup additions of the more volatile components. However, non-azeotropic mixtures may be feasible although significant design changes to the LADDS would be required.

The details of our findings, conclusions, and recommendations are presented in the body of this report.

SECTION 2

INTRODUCTION

2.1 BACKGROUND

The U.S. Army must be able to maintain full operational capabilities on the nuclear, biological, and chemical agent (NBC) contaminated battlefield. A basic but important capability needed to achieve this objective is a mobile system that can provide field laundering and decontamination of soldiers' clothing. Development of such a capability is the responsibility of the U.S. Army Natick Research, Development and Engineering Center (Natick) through it Aero-Mechanical Engineering Directorate.

Standard laundering capability is now provided through the Revised Single Trailer Laundry Unit (RSTLU). However, the RSTLU's effectiveness in decontaminating chemical-agent-contaminated clothing has not been demonstrated. Also, because of the Army's requirements for low-energy consumption and little or no dependence on water supply, Natick initiated efforts to develop a Laundry and Decontamination Drycleaning System (LADDS). The prototype LADDS units were designed to be non-aqueous drycleaning field units integrated with a generator and mounted on a trailer, making the LADDS mobile and independent of outside energy and water sources. The drycleaning solvent on which the LADDS prototype is based is a chlorofluorocarbon (CFC), specifically 1,1,2-trichloro-1,2,2-trifluoroethane or CFC-113. (See Appendix C for information on the ASHRAE system for numbering CFC and related compounds and isomers.)

Since the initial LADDS prototypes were developed, chlorofluorocarbons, including CFC-113, and other chlorine-containing compounds have been linked to the depletion of the stratospheric ozone layer and their production and use will be phased out under U.S. and international regulations. As a result of the imminent loss of availability of CFC-113, Natick, as well as many industrial CFC users, have initiated research efforts to develop or identify alternative solvents or substitute processes. For the LADDS program, Arthur D. Little undertook this study to document current domestic and foreign efforts to develop CFC-113 replacements or solvent alternatives and summarize these alternatives relative to their suitability for use in the present or future LADDS relative to solvent requirements specified by Natick.

2.2 OBJECTIVE AND SCOPE

The objectives of this task were:

- to undertake a thorough and complete search of both domestic and foreign sources to identify and document efforts to develop CFC-113 replacements, and

- to investigate and identify currently available alternative solvents that may be used effectively in the LADDS.

Our approach involved manual and computerized literature data base searches followed by focussed information gathering from industrial, commercial, and government sources through interviews and telephone contacts. The scope of these sources was both domestic and foreign with an emphasis on North America, Europe, and Japan. The literature searches and information gathering process were followed by information compilation and analysis to assess the potential for success of the identified replacements/alternatives relative to the Natick-defined solvent criteria. The results of this information gathering and analysis effort are documented in this report. All information contained in this report was obtained through technical and product literature review, chemical property database searching, and telephone interviews. No laboratory evaluations were performed by Arthur D. Little under this task to generate performance data or to confirm the information provided to us. This report covers both Subtask a and Subtask b of the task scope of work.

The remainder of this report documents our CFC-113 replacement solvent and alternative solvent search efforts and details our conclusions and recommendations regarding potential alternatives. Section 3 describes current CFC and related solvent regulations and recently proposed amendments. Section 4 provides additional background on drycleaning processes and the LADDS solvent requirements. Sections 5 and 6 summarize the solvent search efforts, with Section 7 describing the most promising of these solvent alternatives and technologies identified. Section 8 presents the conclusions and recommendations. Appendices are used to present detailed summaries of the information sources contacted (Appendix A), solvent properties (Appendix B), and fluorocarbon numbering conventions (Appendix C).

SECTION 3

CFC REGULATIONS AND PROPOSED CHANGES

3.1 MONTREAL PROTOCOL AND THE LONDON AMENDMENTS

To address growing scientific and public concerns that certain halogenated compounds are depleting the ozone layer, the United Nations Environment Program (UNEP) began negotiations in 1981 to develop an international agreement to protect the ozone layer. Negotiations throughout the mid-1980s resulted in the Montreal Protocol on Substances that Deplete the Ozone Layer, signed in September 1987 by 24 nations, including the United States. The Montreal Protocol includes provisions to:

- limit the consumption and ultimately ban the production of certain CFCs,

- revise its requirements through scheduled reassessments of the latest technical information on ozone depletion, and

- impose restrictions on trade of ozone-depleting chemicals with non-signatory countries to minimize ozone depletion activities of non-signatory countries.

Shortly after the Montreal Protocol was negotiated, a review of new scientific evidence regarding ozone depletion convinced the signatory countries that further actions were required to expand and strengthen the protocol. Thus, in June 1990, the parties to the Montreal Protocol met in London and agreed to amendments that included additional chemicals for phase-out and accelerated the phase-out schedule for the previously identified compounds. Table 1 summarizes the chemicals targeted by the Montreal Protocol/London Amendments and provides the present phase-out schedules. As Table 1 indicates, CFC-113 is listed as a Group I compound with a phase-out date of January 2000. It is also important to note that Partially Halogenated Fluorocarbons (e.g., HCFCs) are included as transitional substances with phase-out suggested by 2020, if feasible, and 2040 at the latest.

As of January 1992, approximately 70 countries were signatories to the Montreal Protocol. The next meeting of the UNEP Committee is scheduled for Copenhagen, Denmark in October 1992 at which acceleration of the existing phase-out schedules will be discussed.

3.2 U.S. REGULATIONS AND PROPOSED AMENDMENTS

3.2.1 U.S. Clean Air Act Amendments

The U.S. Clean Air Act (CAA) was amended in 1990 with Title VI containing provisions designed to protect the ozone layer through the phase-out of several

TABLE 1
Montreal Protocol/London Amendments Phaseout Schedule

Compound Group*	Phaseout Schedule
Chlorofluorocarbons (Group I - Annex A)	Freeze at 1986 levels by July 1989 20% reduction from 1986 levels by January 1993 50% reduction from 1986 levels by January 1995 85% reduction from 1986 levels by January 1997 100% reduction from 1986 levels by January 2000
Other Chlorofluorocarbons (Group I - Annex B)	20% reduction from 1989 levels by January 1993 85% reduction from 1989 levels by January 1997 100% reduction from 1989 levels by January 2000
Halons (Group II - Annex A)	Freeze at 1986 levels by July 1992 50% reduction from 1986 levels by January 1995 100% reduction from 1986 levels by January 2000 with exemptions for essential uses
Carbon Tetrachloride (Group II - Annex B)	Freeze at 1989 levels by January 1992 85% reduction from 1989 levels by January 1995 100% reduction from 1989 levels by January 2000
Methyl Chloroform (Group II - Annex B)	Freeze at 1989 levels by January 1993 30% reduction from 1989 levels by January 1995 70% reduction from 1989 levels by January 2000 100% reduction from 1989 levels by January 2005
Partially Halogenated Fluorocarbons (Annex C - Transitional Substances)	Resolution calls for use only where other alternatives are not feasible, with phaseout by 2020 if feasible and no later than 2040 (non-binding).

* Group I-Annex A compounds: CFC-11, CFC-12, CFC-113, CFC-114, and CFC-115.
Group I-Annex B compounds: CFC-13, CFC-111, CFC-112, CFC-211, and CFC-211, CFC-212, CFC-213, CFC-214, CFC-215, CFC-216, and CFC-217.
Group II-Annex A compounds: Halon-1211, 1301, and Halon-2402.
Annex C-Transitional Substances: HCFCs.

Source: UNEP, 1991.

suspected ozone-depleting substances. Section 602 of the amendments presents a list of restricted ozone-depleting substances and defines them as Class I and Class II substances. CFC-113 is included as a Class I substance. Class II substances are defined to include 33 HCFCs. Sections 604 and 605 presented the (then current) phaseout schedules for Class I and II compounds, respectively, which were more stringent than those under the Montreal Protocol.

More recently, the United States announced on February 11, 1992 that the phaseout schedule for Class I compounds was being moved up to December 31, 1995 for most end-use applications. U.S. officials also announced that a proposed schedule for accelerating the reduction of Class II HCFC substances would be released for comment. Although the proposal is not expected to be released by the EPA until late March 1992, it is expected to accelerate the phaseout schedules for all Class II HCFC substances (or possibly only HCFC-22, HCF-141b, and HCF-142b) to 2005, instead of the present dates of 2015 for production bans on Class II refrigerants and 2030 for all Class II substances. Several current CFC users and CFC substitute producers have expressed concerns that an acceleration of HCFC phaseout would be costly and that suitable replacements other than HCFCs have not been identified for several end-use applications or will not be commercially available prior to the revised 1995 date for CFC phaseout. As discussed later, several of these Class II HCFCs would be considered leading candidates for CFC-113 alternatives for drycleaning applications.

These regulations focus on production limitations, so that if their use can be controlled or recycled, these compounds may continue in commerce past the above phase-out dates. Other CAA amendments address control of emissions to their lowest achievable levels, safe disposal of controlled substances, prohibitions regarding nonessential products that release Class I and II substances, required labeling of products that contain or were manufactured with Class I or II substances, and establish a policy for evaluating the environmental impact of current and future potential alternatives.

This last requirement, addressed in Section 612 of the CAA amendments, is important to the LADDS project in that the EPA plans to review potential alternatives and categorize their acceptability. Important provisions of Section 612 require EPA to:

- issue rules by November 1992 that prohibit replacing Class I and II substances with substitutes that may adversely affect health or the environment in cases where the EPA has identified an alternative that reduces such risks.

- publish a list of prohibited substitutes and corresponding alternatives by end-use sector, and accept petitions to delete substances listed as prohibited substitutes or add substances as acceptable alternatives.

- require companies producing a Class I substance substitute to notify EPA 90 days before introduction into commerce as a significant new use of that compound, and provide health and safety data on the substitute.

Under Section 612, EPA plans to conduct environmental risk characterizations for substitutes in each end-use sector (e.g., cleaning solvents, foam blowing agents, refrigerants, etc.) and to establish the Significant New Alternatives Program (SNAP) to evaluate future introductions of Class I substitutes. The environmental risk characterizations are to involve a comprehensive analysis of ozone-depleting potential, global warming potential, flammability, toxicity, exposure effects, energy efficiency, pollution and hazardous/solid waste effects, and economic factors. EPA plans to organize these assessments by end-use sector and categorize potential alternatives as unacceptable, acceptable with limitations on use or quantity, acceptable without comment, or delayed pending further study.

In an Advance Notice of Proposed Rulemaking (ANPR), published in the Federal Register on January 16, 1992, EPA proposed a list of key end-use sectors and a list of Class I and II substance substitutes being considered for review under the SNAP program. Relative to the LADDS program, the solvent cleaning use sector was described as:

- Solvent cleaning (e.g., any cleaning operation involving conveyorized vapor degreasing, cold cleaning, and drycleaning)

Solvent alternatives identified in the ANPR for review under the SNAP program included:

- Substitutes for currently used controlled substances (CFC-113, methyl chloroform)
  - alcohols, aqueous, 1,1-dichloroethane, esters, fluoroethers, glycol ethers, glycol ether acetates, HCFC-123, HCFC-141b, HCFC-225ca, HCFC-225cb, HCFC-141b/methanol, hydrocarbon-surfactant, hydrocarbons, ketones, methylene chloride, N-methyl-pyrrolidone, pentafluoropropanol, perchloroethylene, perfluoroalkanes, petroleum distillates, terpenes, terpene alcohols, trichloroethylene, white spirit

- Alternative technologies
  - conductive adhesives, controlled atmosphere soldering, ice particles, low-solid fluxes, no-clean fluxes, no-clean solder pastes, organic acid fluxes, plasma cleaning, pressurized gases, reactive gas soldering, steam cleaning, solderability preservatives (metallic, organic, and polymeric), supercritical fluids, thermal vacuum de-oiling, ultraviolet light/ozone cleaning,

Petitions will be allowed to change the status of a substance based on proof provided by petitioner. The SNAP program will then review future substitutes not covered in this initial risk characterization process.

In addition to the CAA amendments addressing stratospheric ozone depletion, other 1990 amendments address stricter emissions controls of 190 priority pollutants defined under the National Emissions Standards for Hazardous Air Pollutants (NESHAP). Perchloroethylene, the major U.S. commercial drycleaning solvent, is listed as a NESHAP priority pollutant. Under NESHAP, U.S. drycleaners must tighten operations through improved maintenance, leak prevention, and emissions-control equipment. [In related regulatory developments, EPA reclassified perchloroethylene as a potential carcinogen and the Occupational Safety & Health Administration (OSHA) lowered the permissible exposure level (PEL) for perchloroethylene to 25 parts per million (ppm) from 100 ppm in 1991.]

3.2.2 CFC Excise Tax

In addition to the CAA amendments, Congress also placed an excise tax on ozone-depleting chemicals manufactured or imported for use in the United States under the Omnibus Budget Reconciliation Act of 1989. The amount of tax is based on the ozone-depleting potential of the compound and is intended to make these chemicals more expensive to purchase, import, or inventory. For CFC-113, the excise tax, as initially proposed, amounts to $1.10 per pound in 1991 and will increase annually to a level of $3.92 per pound in 1999.

3.3 OTHER INTERNATIONAL PHASEOUT SCHEDULES

Similar to the U.S., several other countries have adopted regulations that are more stringent than the terms of the Montreal Protocol.

Under the Single European Act of 1987, the 12 members of the European Community (EC) are subject to environmental directives including recent ones concerning ozone-depleting compounds. EC countries include Belgium, Denmark, Germany, France, Greece, Great Britain, Ireland, Italy, Luxembourg, the Netherlands, Portugal, and Spain. Council Regulation 594/91, dated March 4, 1991, includes regulatory provisions for the production phaseout of substances that deplete the ozone, including CFC-113. The EC phaseout schedule for CFC-113 production calls for:

- 50% reduction by 1993
- 67.5% reduction by 1995
- 85% reduction by 1996, and
- 100% phaseout by June 30, 1997

While all members must meet these dates, Council Regulation 3322/88, dated October 31, 1988, states that individual EC member countries may enact more extensive requirements.

Germany, for example, has enacted national regulations even more stringent than the EC directives. Under the Emission Control Act (2 BImSch V), all chlorinated solvents including CFC-113, the various HCFCs, methyl chloroform, perchloroethylene, etc. will be prohibited for use after December 31, 1992. Some exemptions have been defined including surface treatment plants, drycleaning and textile finishing, and extraction plants installed before March 1991. Other exemptions may include end use applications with specially sealed machines designed for extremely low emissions or that can demonstrate a lack of suitable alternatives or economic hardship.

The European Free Trade Agreement (EFTA) countries have also adopted more stringent measures to phaseout fully-halogenated ozone-depleting compounds. These countries include Austria, Finland, Iceland, Norway, Sweden, and Switzerland. Some of these countries have adopted end use specific phaseout dates. For example:

- Austria phased out CFC-113 use in some solvent cleaning operations as of January 1, 1992 and all others will be phased out by January 1, 1994

- Norway phased out CFC-113 for all applications except textile drycleaning as of July 1, 1991

- Sweden phased out CFC-113 for all applications except textile drycleaning by January 1, 1991

- Austria, Finland, Norway, and Sweden plan to completely phaseout all uses of CFC-113 by January 1, 1995.

In Canada, all production and import of CFCs for use in Canada must be eliminated by 1997. Environment Canada has also specified target dates for phaseout of CFCs in specific end use applications. For example, use of CFC-113 for solvent cleaning applications must be phased out by the end of 1994.

In Japan, the Ministry of International Trade and Industry (MITI) develops ordinances under the Ozone Layer Protection Act to govern the use of ozone-depleting compounds. MITI and the Japan Environmental Agency developed "Guidelines for Discharge Reduction and Use Rationalization," under which various government agencies provide guidance to industry under their respective jurisdictions.

SECTION 4

LAUNDRY AND DECONTAMINATION DRYCLEANING SYSTEM

This section contains background information on the commercial drycleaning process and a description of the LADDS to provide an understanding of the context in which this program was carried out.

4.1 DESCRIPTION OF THE GENERAL DRYCLEANING PROCESS/EQUIPMENT

Textile drycleaning equipment performs three prime functions:

- clean the textile articles through soil removal,
- completely dry the items before removal from the machine, and
- purify the drycleaning solvent for reuse.

Commercial drycleaning is used to clean textiles whose fibers and weave might be distorted or otherwise damaged if cleaned with water. Water cleaning of many materials can affect the stability of fabric, lining and interlining. In some cases, it can also cause either excessive shrinking or stretching. Drycleaning operations also include a number of other processes such as stain removal, heavy soil removal, tailoring, processing, and ironing. In order to control operating costs, low solvent use and high-energy efficiency have been important factors in the design and purchase of commercial drycleaning equipment. Also, environmental regulations have pushed equipment designers to greatly reduce work area solvent concentrations and vapor releases into the environment. Present drycleaning machines operate as totally enclosed systems, which incorporate filtration, distillation, and refrigerated recovery systems.

Commercial fabrics often specify the following drycleaning category on the label:

A. May be safely cleaned in 1,1,1-trichloroethane (also called methyl chloroform). Only a few garments carry this designation since trichloroethane is a strong solvent.

P. Most garments have this designation and can be cleaned in perchloroethylene or CFC-113.

F. Garments in this category are delicate and can be cleaned only in CFC-113.

The general trend in the drycleaning industry is towards the increased use of perchloroethylene as CFC-113 is phased out. Garment manufacturers now realize that certain fabrics that can only be cleaned in CFC-113 might be phased out in the future, since they will not be able to be cleaned. Because of regulations restricting general halogenated solvent use (e.g., in Germany), increased efforts are also being directed toward commercial uses of hydrocarbon-based solvents. Some work is currently underway to develop drycleaning equipment that uses such high-boiling, flammable solvents.

4.2 CURRENT LADDS DESIGN AND FUTURE REQUIREMENTS

The prototype LADDS units were designed to be nonaqueous drycleaning field units using CFC-113, or an equivalent cleaning fluid. The present prototype unit is comprised of a washing system and a diesel-engine-driven generator. The components are mounted on a trailer making the system mobile and independent of outside energy sources or an outside water supply. The LADDS is intended to be capable of removing chemical agents from clothing made of both conventional and special fabrics. Provisions have been made for handling of NBC materials that might be collected in the CFC-113 or other cleaning fluid. The major objective of this study was to identify fluids, either commercially available or in the developmental stages, that can be substituted for CFC-113 in the current LADDS process. A detailed description of the current LADDS prototype unit was provided previously in RFP DAAK60-91-R-2015.

In general, the LADDS was designed to clean and decontaminate (i.e., remove NBC contamination from) clothing and fabric items at a rate of 200 pounds per hour. This process requirement is achieved by performing two 100-pound cleaning cycles per hour (wash, rinse, extract, and dry). Each wash and rinse requires approximately 30 gallons of solvent each. The solvent used in the washing stage will contain a heavy concentration of dirt, oils, detergent and NBC contamination, and is transferred to a holding tank (Dump Tank) at the completion of the wash segment. The contaminated solvent is fed to the solvent distillation and neutralization system (SDANS) by gravity from the Dump Tank for distillation and neutralization of any chemical agent. Once distilled, the clean solvent is transferred from the SDANS to the Rinse Tank. The solvent used during the rinse segment is drawn from the Rinse Tank and at the completion of this segment is transferred to a third holding tank (Wash Tank) where it is held for use during the wash segment of the following cleaning cycle. The process described above allows the continuous reuse of the cleaning solvent, reducing logistical burdens in the field.

Based on the results of this program, as will be discussed in later sections of this report, the U.S. Army may need to consider design modifications in future LADDS systems. For example, if a decision is made to use a nonazeotropic solvent mixture, then provisions will be required for batch distillation, fluid composition monitoring, and make up solvent additions. Also, operation with water-based cleaners or other high-boiling solvents may be desirable.

4.3 CFC-113 REPLACEMENT SOLVENT SELECTION CRITERIA

The replacement solvent selection criteria specified by Natick were defined to mimic the properties of CFC-113 as closely as possibly while also providing environmental acceptability. For some properties, specific criteria were defined. For several criteria, however, desired properties were only vaguely defined.

CFC-113 solvent selection criteria specified by Natick were:

- Solvent reusability
  - preferred boiling point in range from 120°F-150°F, but would also consider compounds in the broader range from 80°F-165°F
  - low heat of vaporization, similar to the CFC-113 value of 36.1 Kcal/Kg
- Selectivity/Compatibility/Noncorrosivity
  - dissolve soils without harming fabrics or equipment
  - noncorrosive
  - dissolve chemical agents over wide range of temperatures
- Safety
  - nontoxic
  - nonflammable
- Environmentally acceptable
- Economically acceptable

Although discussed during the course of this project, specific Natick criteria for assessing safety, environmental, and economic acceptability were not defined. Nonflammability of the solvent alternative was designated as a priority criteria while solvent alternatives were not to be excluded, at this stage, based on toxicity information. Natick also agreed that fluids that did not meet all of the above solvent reusability criteria should not be omitted for the purposes of this study. For example, perchloroethylene, which has a boiling point of 250°F, is clearly outside of the desired boiling point range but was included because of its current use in the majority of commercial drycleaning applications.

SECTION 5

CFC-113 REPLACEMENT SOLVENT SEARCH (TASK 1A)

5.1 APPROACH

Efforts on this subtask included literature data base searches followed by information gathering from industrial, commercial, and government sources through telephone interviews. The scope of these sources was both domestic and foreign with an emphasis on North America, Europe, and Japan. The results of these information gathering efforts are documented here, with this section summarizing present CFC-113 replacement activities and Section 6 summarizing our findings regarding alternative solvents that may be suitable for use in the present or future LADDS. Also, as described below, Appendix A provides detailed information on the sources contacted and Appendix B provides detailed information on the CFC-113 alternatives identified.

5.2 INFORMATION SOURCES

At the start of the program, a computerized search of on-line information databases was undertaken to identify industrial, government, and association sources active in this area. Efforts by these information sources to develop CFC-113 replacements were documented through telephone interviews as well as obtaining technical articles and information releases identified by the literature search. Relevant technical articles and reports identified during this effort are listed in the Bibliography section of this report. Another important information source was through attendance at the presentations and exhibits at the 1991 International CFC and Halon Alternatives Conference and Exhibition on December 3-5, 1991 in Baltimore, MD.

The literature search strategy involved searching over the time period from 1990 to present initially and was later extended to include from 1985 to present. The keywords used were:

- CFC or Chlorofluorocarbon or Flon (truncated when necessary)
- combined with 113 (as two separate terms, as well as a compound term), and
- within a specified number of words of the terms: Alternat, Replac, or Substitut (the last three terms were truncated to pick up all endings)
- Dryclean or Clean (truncated) was also combined with the CFC terms or Solvent and the Alternat/Replac/Substitut combination

The databases searched were:

- Business Dateline
- Chemical Abstracts
- Chemical Business Newsbase (Royal Soc Chem)
- Energy Science & Technology
- Federal Research in Progress
- Industry Notes (American Chemical Society)
- INFOMAT International Business
- INSPEC (The Database for Physics, Electronics and Computing)
- Japan Technology
- NASA
- Pollution Abstracts
- Predicasts Overview of Markets and Technology (PTS PROMPT)
- PTS Newsletter Database
- Textile Technology Digest
- Toxlit
- Trade & Industry Index and Trade & Industry ASAP

Tables 2 through 4 summarize the information sources identified and contacted during this project and categorizes them by general type of organization. Although over 75 information sources were identified, we present these sources as a best efforts attempt to identify sources most directly applicable to the LADDS solvent requirements and should be considered a representative summary of CFC-113 replacement activities. Table 2 lists United States/North American sources, Table 3 lists European sources, and Table 4 lists Japanese and Asian sources. For simplicity, four organization-type categories were used: chemical producer, equipment manufacturer, government agency, or association/research institute. A one-page profile of each of these organizations regarding their CFC-113 replacement solvent activities is provided in Appendix A. The profiles are presented in alphabetical order and an index to the profiles is provided at the end of Appendix A.

5.3 SUMMARY OF FINDINGS

Most current activities to develop CFC-113 replacements are targeted toward solvent cleaning of metal or electronics parts, which had been the major solvent uses for CFC-113. While organic solvents, particularly HCFCs are being pursued, many previous CFC-113 users have adopted, plan to adopt, or are evaluating aqueous and semiaqueous-based cleaning systems. Although these cleaning systems have required equipment and/or process changes, many companies believe that this route is the only long-term, safe, and environmentally-acceptable alternative available to them. Also, when feasible, manufacturers are adopting alternative processes or technologies to eliminate the need for cleaning processes.

TABLE 2
United States/North American Information Sources*

Organization	Type
AGFA-Gevaert, Inc.	Equipment manufacturer
Allied-Signal, Inc.	Chemical producer
Alternative Fluorocarbons Environmental Acceptability Study (AFEAS)	Association/research inst.
American Telephone & Telegraph	Equipment manufacturer
Arakawa Chemical (USA), Inc.	Chemical producer
Asahi Glass America, Inc.	Chemical producer
Ashland Chemical, Inc.	Chemical producer
Clemson University	Association/research inst.
Columbia Machine Corporation	Equipment manufacturer
Detrex Corporation	Equipment manufacturer
Digital Equipment Corporation	Equipment manufacturer
Dow Chemical Company	Chemical producer
E. I. duPont de Nemours and Company	Chemical producer
Electric Power Research Institute (EPRI)	Association/research inst.
Elf Atochem North America, Inc.	Chemical producer
Envirosolv Inc.	Chemical producer
Exxon Chemical Company (Exxon Chemical Canada)	Chemical producer
Grace Equipment Corporation	Equipment manufacturer
Halocarbon Products	Chemical producer
Hoechst Celanese Corporation	Chemical producer
Hurri Kleen Corporation	Chemical producer
ICI Americas, Inc.	Chemical producer
Industry Cooperative for Ozone Layer Protection (ICOLP)	Association/research inst.
International Fabricare Institute (IFI)	Association/research inst.
ISP (formerly GAF Chemicals)	Chemical producer
Martin Marietta	Equipment manufacturer
Molecular Knowledge Systems	Association/research inst.
Northern Telecom (Canada)	Equipment manufacturer
PCR Inc.	Chemical producer
Petroferm	Chemical producer
Program for Alternative Fluorocarbon Testing (PAFT)	Association/research inst.
Safety-Kleen	Chemical producer
SCM-Glidco	Chemical producer
3M	Chemical producer
Union Camp	Chemical producer
U.S. Air Force/Halon Alternatives Program	Government agency

(continued)

TABLE 2
United States/North American Information Sources*

Organization	Type
U.S. Army Chemical Research, Development & Engineering Laboratory (CRDEC)	Government agency
U.S. Dept. of Energy/Oak Ridge National Laboratory	Government agency
U.S. EPA/Air and Energy Research Laboratory	Government agency
U.S. National Aeronautics and Space Administration (NASA)/Kennedy Space Center	Government agency
University of Tennessee	Association/research inst.
Vulcan Chemical	Chemical producer
W.R. Grace & Co.	Chemical producer

* See Appendix A for one-page profile of each organization regarding their current activities to develop, evaluate, or use CFC-113 replacements.

TABLE 3
European Information Sources*

Organization (Location)	Type
Agfa-Gevaert (Belgium)	Equipment manufacturer
Akzo Chemicals (Netherlands)	Chemical producer
Bayer AG (Germany)	Chemical producer
British Aerospace Dynamics (Great Britain)	Equipment manufacturer
British Petroleum Ltd. (Great Britain)	Chemical producer
Bush Boake Allen Ltd. (Great Britain)	Chemical producer
Chimie Innovations et Technologies (France)**	Chemical producer
CTTN - IREN (France)	Association/research inst.
Danish Clothing and Textile Institute (Denmark)	Association/research inst.
Deutsche Shell Chemie (Germany)	Chemical producer
Elf Atochem (France)	Chemical producer
European Committee of Laundry and Dry Cleaning (Great Britain)**	Association/research inst.
European Fluorocarbon Technical Committee (Belgium)**	Association/research inst.
European Laundry and Dry Cleaning Machinery Manufacturers Organization (Italy)	Association/research inst.
Fabric Care Research Association (Great Britain)	Association/research inst.
Hoechst Celanese Corporation (Germany)	Chemical producer
Hohenstein Institute (Germany)	Association/research inst.
Hohere Bundes-Lehr u. Versuchsanstalt fur Textilindustrie (Austria)	Association/research inst.
HRPR Exports Ltd. (Great Britain)	Equipment manufacturer
Imperial Chemicals Industries (Great Britain)	Chemical producer
International Drycleaning Research Committee (France)	Association/research inst.
KLN Ultraschall GmbH (Germany)	Equipment manufacturer
Montefluos S.P.A. (Italy)	Chemical producer
Phillips (Netherlands)**	Equipment manufacturer
Protonique SA (Switzerland)	Equipment manufacturer
Research Institute for Cleaning Technology (Germany)	Association/research inst.
Rhone-Poulenc Chemicals, Ltd. (Great Britain)	Chemical producer
SCM-Glidco	Chemical producer
Sketchley Plc. (Great Britain)	Dry Cleaner
Swedish Institute for Textile Research (Sweden)	Association/research inst.
Textile Services Association Ltd. (Great Britain)	Association/research inst.

* See Appendix A for one-page profile of each organization regarding their current activities to develop, evaluate, or use CFC-113 replacements.

** Included in Appendix A; however, attempts to contact appropriate representatives were unsuccessful over the task duration.

TABLE 4
Japanese/Asian Information Sources*

Organization	Type
All Japan Laundry & Dry Cleaning Association	Association/research inst.
Arakawa Chemical Industries, Ltd.	Chemical producer
Asahi Glass	Chemical producer
Central Glass**	Chemical producer
Chemical Technology Research	Association/research inst.
Daikin Industries**	Chemical producer
DuPont-Mitsui Fluorochemicals	Chemical producer
Ebara	Equipment manufacturer
Hitachi Ltd.	Equipment manufacturer
Japan Association for Hygiene of Chlorinated Solvents	Association/research inst.
Japan Industry Cooperative for Ozone Protection	Association/research inst.
Kanto Denka Kogyo Co., Ltd.	Chemical producer
Matsushita-Kotbuki Electronic Ind.	Equipment manufacturer
Showa Denko	Chemical producer
Toshiba Research and Development Center	Equipment manufacturer
Ulsan (South Korea)**	Chemical producer

* See Appendix A for one-page profile of each organization regarding their current activities to develop, evaluate, or use CFC-113 replacements.

** Included in Appendix A; however, attempts to contact appropriate representatives were unsuccessful over the task duration.

5.3.1 Findings by End-Use Application

Drycleaning --

Current CFC-113 users, the majority of which are in Europe, appear to be moving toward perchloroethylene systems even though emissions of this compound are tightly regulated as a suspect carcinogen. Most commercial drycleaners in the U.S. and Japan now use perchloroethylene (International Fabricare Institute, All Japan Laundry & Drycleaning Association). Essentially all drycleaners in Germany also had converted over to perchloroethylene. However, German regulations prohibit the use of chlorinated compounds after December 1992 for most applications. It is not certain whether drycleaning applications will be exempted (Hohenstein Institute, Research Institute for Cleaning Technology). Approximately 25% of the drycleaners in Great Britain are CFC-113 users, down from 30% in 1989, with most of these users planning to convert to perchloroethylene systems in the future (Fabric Care Research Association, Sketchly).

Research efforts in the drycleaning industry appear to be focussing on equipment improvements to reduce emissions and potential worker exposures (Columbia, Grace), although some companies (Allied-Signal, Akzo, Asahi) are pursuing HCFCs as drop-in replacements for CFC-113 in existing drycleaning equipment. Higher boiling hydrocarbons are also gaining favor as replacement solvents for both CFC-113 and perchloroethylene, with equipment modification efforts to address flammability issues (Research Institute for Cleaning Technology). As with the LADDS design requirements, nonflammability of the drycleaning solvent is an important criteria for any substitute solvent. In general, all solvent users interviewed described that reductions in the use and emissions of volatile organic solvents, particularly those designated as hazardous wastes, were a priority.

Metal Parts and Electronic Assembly Cleaning --

To date, several alternative solvents and processes have been developed that provide equal cleaning performance to CFC-113 for general cleaning requirements at acceptable cost. Many of these alternatives involve aqueous and semiaqueous cleaning systems that have required equipment modifications for multistage washing and drying, particularly to address corrosion prevention during drying of complex parts (AT&T, Digital, Northern Telecom). In the electronics industry, alternative manufacturing processes such as low-solids and no-clean flux, water-soluble flux, and controlled atmosphere soldering have been developed to eliminate the need for solvent cleaning altogether.

Precision Cleaning --

Precision cleaning involves the cleaning of high-precision mechanical and electronic devices, generally done under controlled atmospheres, to specifically defined tolerances. Precision cleaning operations are critical to the aerospace, defense, electronics and medical industries. CFC-113 and 1,1,1-trichloroethane were widely used because of requirements to clean small parts with zero solvent or soil residues and fast drying. While aqueous and semiaqueous cleaning systems have been proposed for this application, they have not been widely accepted because of rinsing and drying concerns, although some manufacturers have demonstrated acceptable performance and have adopted such systems (Digital Equipment). Alcohol-based systems, HCFCs, and hydrocarbons are also under evaluation. Alternative cleaning processes under development include plasma cleaning, pressurized gases, supercritical fluids, and ultraviolet/ozone cleaning methods.

Other End Uses --
There are also significant research and development efforts, both domestic and foreign, in progress to identify CFC replacements for other end-use applications. These include replacements for foam blowing agents, refrigerants, air-conditioning fluids, halons (U.S. Air Force), and aerosols. These end-uses, however, traditionally have not used CFC-113, but use other CFCs whose physical properties are quite different from the LADDS requirements. Consequently, the target replacements or alternatives generally are not suitable for use in the LADDS. Some compounds, however, being developed as halon or foam blowing agent replacements may be suitable. These compounds include HCFCs, HFCs, and perfluorocarbons described further below.

5.3.2 Findings by Replacement Solvent Type

CFC-113 replacements described by the above information sources as either commercially available now or in the near future can be categorized into approximately ten solvent types. These general solvent types are described briefly below. The specific candidates most closely meeting the LADDS requirements described in more detail in Section 7.

Appendix B also summarizes available technical information on specific compounds and commercial products within each of these categories. The Appendix B data table includes information on chemical identity and acceptability relative to Natick requirements. Chemical identity information includes chemical or product name, ASHRAE designation, Chemical Abstract Service (CAS) Registry number, chemical composition or formula, and manufacturer(s), when applicable or available. Acceptability information includes data on environmental acceptability (ODP and GWP), physical properties, flammability, toxicity, cleaning effectiveness and materials compatibility, and commercial availability.

Hydrochlorofluorocarbons (HCFCs) --
HCFCs have been regarded as the most technically-feasible, short-term replacements for CFC-113, although recent changes in proposed phase-out schedules have seriously impacted several manufacturers' decisions to move ahead with these compounds (Akzo, Allied, Asahi, Central, Daikin, DuPont, Elf Atochem, Halocarbon, Hoechst Celanese, ICI, Montefluos, Showa Denko). Several of the HCFCs (HCFC-123, 141b, and the various 225 isomers) closely match CFC-113's physical properties although test results regarding their potential toxicity will not be available until 1993

(PAFT). HCFCs are also being pursued as components of azeotropic mixtures (Allied, DuPont).

Hydrofluorocarbons (HFCs) --

HFCs are not considered ozone-depleting compounds and are not regulated for phase-out. While several organizations (Asahi, EPA/EPRI/Clemson University, PCR, and 3M) are researching these compounds, few HFCs are available on a commercial scale. Several HFCs have been identified with boiling points within the range desired by Natick. However, little is known regarding their solvating properties, and toxicity or flammability limitations. Further investigation of these compounds may be warranted as long-term LADDS solvent alternatives.

Perfluorocarbons (FCs) --

Perfluorocarbons are commercially available (Rhone-Poulenc, 3M) with boiling points and heats of vaporization within the ranges desired by Natick (perfluorohexane through perfluoroctane). While these compounds are non-flammable and exhibit low toxicity, they have extremely poor solvating properties and are expected to perform poorly as drycleaning solvents. These compounds, however, may be beneficial as mixture components to stabilize or balance the aggressiveness of other solvents or to reduce the flammability of solvent mixtures.

Other Fluorinated Compounds --

Other fluorinated compounds under development that may be suitable as LADDS solvents include fluorinated ethanols (Halocarbon, Inc.), fluorinated propanol (Nikon), fluorinated ethers (EPA/EPRI/University of Tennessee), and perfluorinated morpholines (3M). While few of these compounds are now commercially available, several closely match CFC-113's physical properties and provide good solvating properties. Little information is available, however, regarding their flammability and toxicity.

Other Chlorinated Solvents --

Perchloroethylene is the major solvent used today in the drycleaning industry (International Fabricare Institute, Dow). Perchloroethylene has a higher boiling point and heat of vaporization than those desired by Natick and has been designated by EPA as a suspect carcinogen. In 1991, OSHA reduced the PEL for perchloroethylene to 25 ppm. Other chlorinated solvents, such as 1,1-dichloroethane and trichloroethylene, are being used in some cleaning applications although these compounds face strict emissions and waste disposal controls, and in some countries (Germany), are targeted for production phaseouts.

Hydrocarbons --

High-boiling, high flash point hydrocarbons are being used as CFC-113 replacements for some metal and electronic parts cleaning applications (DuPont, Exxon, Shell). Petroleum distillates, such as mineral spirits, have also been used as drycleaning solvents. However, their high boiling points exceed the range desired for the LADDS replacement solvent. Because of their potential flammability, hydrocarbon cleaners used for metal/electronic cleaning applications are used either at room temperature or up to temperatures 15°C below their flash point. Drying is typically performed using forced hot air, again at 15°C below the flash point, with a recovery step to control VOC emissions.

Alcohols --

Alcohol-based cleaning systems are being pursued for metal and electronic parts cleaning applications (British Aerospace Dynamics, ICI, and many Swedish industries). While alcohols have excellent solvent power, their use is limited because of their flammability (except for several high molecular weight, high boiling, slow drying alcohols). Several companies are working to develop explosion-proof cleaning equipment for use with alcohols (British Aerospace Dynamics, KLN Ultraschall). Alcohols in the boiling point range desired by Natick are flammable.

Aqueous Cleaning Systems --

A large number of equipment manufacturers are converting to aqueous-based cleaning systems. They believe water-based cleaning is the most environmentally acceptable, cost effective, long-term alternative available to them, particularly in light of CFC/HCFC phaseouts and other regulations to control the use, emissions, and disposal of organic solvents. Aqueous cleaning systems include alkaline degreasers and various detergent/saponifier formulations (Digital Equipment Corporation, Hurri Kleen, Martin Marietta, W.R. Grace). A water-based system may be feasible as an alternative LADDS solvent, although its higher boiling point and heat of vaporization would increase energy requirements and would require design modifications.

Semiaqueous or Hydrocarbon/Surfactant Systems --

Both names are used to describe cleaning systems that employ a hydrocarbon or other organic solvent cleaner in a wash stage followed by an aqueous rinsing stage to remove solvent residues and water-soluble soils. These solvent cleaners can be glycol ethers and glycol ether acetates (British Pertroleum, Dow, Phillips), hydrocarbons (Detrex, DuPont, Exxon), lactate or aliphatic esters (Exxon, Purac), pyrollidones (ISP), or terpenes (Arakawa, Bush Boake Allen/Union Camp, Envirosolv, Petroferm, SCM-Glidco). While these compounds have been found to be good cleaners, they typically have high boiling points, moderate flash points, and may cause fiber swelling during textile cleaning because of their hydrophilic nature.

Mixtures and Azeotropes --

Several manufacturers also described azeotropic mixtures of HCFCs, hydrocarbons, chlorinated solvents, and/or alcohols (Allied, DuPont, ICI) available commercially as CFC-113 alternatives for solvent cleaning applications.

SECTION 6

ALTERNATIVE SOLVENT SEARCH (TASK 1B)

6.1 APPROACH

In addition to the CFC-113 replacement information gathering activities described in Section 5, we also undertook database searches and interviews to identify other commercially-available solvents that may be suitable for use in the LADDS but that were not being specifically evaluated by industry as CFC-113 replacements. This alternative solvent search was undertaken primarily by attempting to identify compounds, from any source, that matched the solvent properties criteria outlined in Section 4.3. Our approach involved two main components: chemical property database searching and telephone interviews with solvent producers.

6.2 DIPPR-AICHE AND BEILSTEIN DATABASES

Two on-line chemical property databases, with access available through STN International, were searched:

- DIPPR-AIChE--a database of textual and numeric pure component physical property data compiled by the Design Institute for Physical Property Data (DIPPR) of the American Institute of Chemical Engineers (AIChE), and

- BEILSTEIN--a database of chemical information including synthesis, thermodynamic data, toxicity information, and multicomponent system data compiled from the Beilstein Handbook of Organic Chemistry and the scientific literature.

As of February 1992, the DIPPR-AIChE database contains detailed chemical and thermodynamic property records for approximately 1200 compounds. The BEILSTEIN chemical property database includes over 3,000,000 compounds. However, only very limited thermodynamic property data are included. The BEILSTEIN database does not include data fields describing flammability properties, although Beilstein does include a field that allows one to search toxicity information.

6.3 SUMMARY OF FINDINGS

Table 5 summarizes the numbers of compounds reported by these databases, to fall within the boiling point range, 80-165°F, defined as potentially acceptable for the LADDS solvent. Table 5 also indicates the numbers of compounds identified to fall within the desired boiling point range of 120-150°F. Although many compounds were identified within the preferred boiling range, detailed searches were unsuccessful in identifying compounds that matched all or most of the Natick requirements. In general, the deficiencies were due to flammability requirements or because data on several key criteria are not available.

TABLE 5
Compounds Identified Using DIPPR and BEILSTEIN Databases with Boiling Point within 80-165°F

Boiling Point (°F)	# of Chemicals	
	DIPPR	BEILSTEIN
80 - 99	26	6,259
100 - 119	30	15,744
120 - 150	47	46,753
151 - 165	32	33,113
80 - 165	132	84,407
Total compounds in data base	1212	3,417,112

For DIPPR, search criteria were first defined using boiling point range and minimum flash point criteria and requested output of three other properties: heat of vaporization, flammability range (if applicable), and solubility parameter. We found, however, that inclusion of the flash point field in the search criteria eliminated some nonflammable compounds because of limitations in field searching capabilities (for example, one may search by flashpoint, but entries reported as "Not Applicable" or "Non-Flammable" would not be found; only records with specific values would be identified). Consequently, later searches used only boiling point and heat of vaporization as criteria. As reported in Table 6, seven possible compounds were identified. These compounds were acetone, acrolein, ethyl formate, methanol, methyl acetate, methyl tert-butyl ether, and tetrahydrofuran. Data on these compounds are included in the Appendix B data table. However, they do not appear to be suitable LADDS solvent alternatives because they are all flammable or combustible solvents.

For the BEILSTEIN database search, we followed the same search strategy of defining only the boiling point range and a heat of vaporization target. Table 6 indicates that 110 compounds were identified by this search. Because BEILSTEIN does not include flashpoint or flammability information, other sources were used to screen these properties. Of these 110 compounds, only 10 are included in the Appendix B data table and, of these, none appear to match all or most of the Natick solvent property criteria.

TABLE 6
Compounds Identified Using DIPPR and BEILSTEIN Databases Using Boiling Point and Heat of Vaporization Criteria

Boiling Point (°F)	Heat of Vaporization (KJ/mol)	# of Chemicals	
		DIPPR	BEILSTEIN
120 - 165	--	76	71,601
120 - 165	<42	7	241
120 - 165	<33.5	6	110
Total compounds in data base		1212	3,417,112

As part of this subtask, we also discussed alternative solvent identification efforts with major U.S., European, and Japanese chemical producers through the interviews described in Section 5. In essence, searches based on physical property matching are one of the important approaches used by these chemical producers to identify the currently available CFC-113 replacements as well as "next generation" solvents that they are working on. None of these chemical producers would reveal the identity, general chemical class, or physical property information regarding next generation solvents at this time. One exception was 3M, who described efforts to better understand and commercialize perhalogenated morpholines (e.g., perhalogenated-N-methylmorpholine, boiling point=122°F, heat of vaporization=25 kcal/kg), however, very little information is available regarding its toxicity, flammability, cleaning performance, or materials compatibility.

It is important to note that this alternative solvent search was limited by the contents of the physical property databases now available as well as chemical producers unwillingness to reveal solvent information prior to commercialization. For example, neither the DIPPR nor the BEILSTEIN databases included several of the HCFCs currently pursued by industry and providing the closest match to CFC-113's physical properties. Another route to identify compounds that Natick may want to pursue is to use predictive approaches to estimate properties for compounds not included in current databases and to identify potential chemicals or chemical mixtures not now commercialized that would be important for future research and development activities. Such approaches have been described (U.S. Air Force, Molecular Knowledge Systems) for other applications and may be useful here.

SECTION 7

POTENTIAL REPLACEMENT SOLVENTS

7.1 SOLVENTS

The potential replacement solvents described below were selected in accordance with the CFC-113 replacement solvent selection criteria given in Section 4.3. Table 7 summarizes the properties of potential near-term LADDS solvent alternatives, whereas Table 8 summarizes potential long-term solvent replacements. Brief descriptions of these candidate replacements follow:

- HCFC-123 has a low boiling point relative to the LADDS desired range and is a very aggressive solvent. Also, initial toxicity test results have resulted in projected PEL (TLV-TWA) values by the manufacturer of 10 ppm. Further results will be available from PAFT studies in 1993. HCFC-123 is commercially available in the U.S.

- HCFC-141b also has a low boiling point, is combustible, and is an aggressive solvent. Some question also remains about toxicity. An earlier phaseout schedule is anticipated for the compound as EPA develops proposed amendments to current HCFC phaseout schedule based on their ODP. Since HCFC-141b has a high ODP, it most likely will be subject to earlier phaseout, possibly in the year 2005. HCFC-141b is currently available from several U.S. suppliers.

- HCFC-225 and its various isomers appear to be the closest match to the solvent selection criteria presently defined by Natick. HCFC-225 has a boiling point similar to CFC-113, has about the same textile cleaning ability and solvent strength, and is nonflammable. Some performance deficiencies may exist, however, relative to its stability in the presence of bleach or similar decontamination agents. Some questions also remain about its toxicity resulting from preliminary tests, again with more detailed test results expected in 1993 from PAFT. DuPont has decided not to produce HCFC-225 because of these current uncertainties. However, HCFC-225 might be available from other U.S. suppliers and from Japan on a reliable basis until phase out.

Other solvents, currently used in drycleaning and laundering applications, may also be suitable as LADDS solvent replacements, although significant changes to the LADDS design may be necessary to use these alternatives.

TABLE 7
Summary of CFC-113 Replacement Data for Near-term Substitutes

	CFC-113	HCFC-123	HCFC-141b	HCFC-225 (several isomers)
Boiling point °F, (°C)	118 (47.8)	82-84 (28-29)	89-90 (31.7-32.2)	124-133 (51-56)
BTU/gallon to boiling *	1160	902	1010	940-980
Kauri butanol value	31	60	58	30-34
Textile Cleaning Performance **				
• Cleanability	Good	Good	Good	Good
• Redeposition	Good	Good	Good	Good
• Effect on:				
– flock fabrics	Good	Good	Good	Good
– Lamé	Good	Good	Good	Good
– Acetate	Good	Poor	Good	Good
– Nylon	Good	Good	Good	Good
– Acrylic	Good	Good	Good	Good
Compatibility with metals	Good	Good	Good	Good
Toxicity (PEL) +	1000	10	--	--
Flammable	No	No	Combustible	No
ODP ++	0.8	0.02	0.15	.05
GWP ++	1.3	0.02	0.09	0.03 to 1.0

Notes:

* Heat required to boil one gallon of solvent from 20°C.
** Source: Akzo/Asahi.
+ Threshold limiting value, permissible exposure limit in ppm,
-- indicates PEL not yet established.
++ Based on CFC-11 equal to 1.0.

TABLE 8
Summary of CFC-113 Replacement Data for Possible Long-term Substitutes

	Hydrocarbon Solvents	Perchloro-ethylene	Aqueous Cleaners
Boiling point °F, (°C)	157-196 (69-91)	250 (121.1)	>212 (>100)
BTU/gallon to boiling *	NA	2090	--
Kauri butanol value	36	90	--
Textile Cleaning Performance **			
• Cleanability	Good	Good	Good
• Redeposition	Good	Good	Good
• Effect on textiles	Good	Good	Varies
Compatibility with metals	Good	Good	Good
Toxicity (PEL) +	Varies	25	None
Flammable	Yes	No	No
ODP ++	0	0	0
GWP ++	NA	NA	0

Notes:

* Heat required to boil one gallon of solvent from 20°C.
** Source: International Fabricare Institute.
\+ Threshold limiting value, permissible exposure limit in ppm.
++ Based on CFC-11 equal to 1.0. NA = Not available.

- Perchloroethylene - This solvent is the most commonly used commercial drycleaning solvent despite its high boiling point and energy consumption relative to CFC-113. Perchloroethylene has proven performance as a textile cleaning solvent, but is a stronger solvent than CFC-113 and may not be suitable as a direct substitute for all applications. Although emissions of perchloroethylene are regulated, modern drycleaning equipment is designed so that emissions are low and recovery is highly efficient. Most drycleaners using CFC-113 are changing over to perchloroethylene. Although perchloroethylene does not meet the specified Natick boiling point requirement, it should be given a thorough evaluation as an alternative solvent for the LADDS.

- Hydrocarbon Solvents - While such compounds are much higher boiling than desired and flammable, several commercial drycleaners and equipment producers, particularly in Germany, are focussing drycleaning research and development efforts on hydrocarbon solvents because of restrictions on halogenated compound use. These solvents are also covered by EPA regulations which limit hydrocarbon emissions. Some work is being carried out in Europe to improve equipment design to better control flammability and solvent emissions.

- Aqueous Cleaners are presently being used for various metal and electronic parts cleaning. In addition to water, they usually include alcohols, alcohol ethers, other water-miscible solvents and detergents to lower the surface tension to improve wetting and cleaning. The volatile, water-miscible solvents serve to promote drying. Again, review of design requirements to address increased energy consumption would be required to assess the feasibility of this approach.

Other potential long-term solvent alternatives include the use of FCs, HFCs, and fluorinated alcohols, ethers, and other organic compounds. Several fluorinated compounds have been identified with boiling points within the range desired by Natick. However, only very limited data are available regarding their flammability and toxicity. Also, cleaning performance and compatibility with LADDS materials of construction of these compounds would need to be established. It is expected that some miscibility problems will be experienced with the use of FCs and HFCs since they tend not to blend with other solvents. The FCs also are not expected to be good cleaning agents since they do not readily dissolve soil and contaminants.

7.2 MIXTURES AND AZEOTROPES

Mixtures and azeotropes now in use commercially have been designed for cleaning electronic and mechanical components. In their present formulations, these mixtures and azeotropes may not be suitable for use in the LADDS. Also, the most common types are based on HCFC-141b and it is anticipated that this fluid will be targeted for early phase out because of its high ODP. Fluorinated alcohols mixed with HCFCs and water are being evaluated in Japan. As discussed below, the use of nonazeotropic mixtures will require major changes in the LADDS design.

7.3 ENGINEERING DESIGN AND CONTROLS

If HCFC-225 is chosen as the LADDS replacement solvent, the operating requirements should be similar to those of the present LADDS since the boiling points and heat of vaporization are similar to that of CFC-113. Thus, HCFC-225 could be considered as a "drop-in" replacement for CFC-113. If any of the higher-boiling solvents described in Section 7.1 are to be pursued, several advantages and disadvantages should be considered from an overall design standpoint. The advantages are that such higher-boiling solvents are easier to recover and should give lower solvent losses during processing. The efficiency of recovery would also be higher. The disadvantages are that more energy will be required for recovery and the drying time per laundry load will be longer.

SECTION 8

CONCLUSIONS AND RECOMMENDATIONS

Although it is difficult to predict the future course and timing of the regulations to phase out the production and use of CFCs and HCFCs, the following discussion is based on our findings as of February 1992. Although this study was aimed at identifying CFC-113 substitutes for the LADDS process, the conclusions and recommendations are in general agreement with the course being taken by the commercial drycleaning industries in the U.S., Europe, and Japan.

8.1 CONCLUSIONS

Many solvents and solvent mixtures are being pursued by industry as CFC-113 replacements. These include alcohols; aqueous cleaning systems; chlorinated solvents including dichloroethane, perchloroethylene, and trichloroethylene; hydrocarbons; hydrochlorofluorocarbons (HCFCs); hydrofluorocarbons (HFCs); perfluorocarbons (FCs); other fluorinated compounds including fluorinated alcohols, ethers, and morpholines; semi-aqueous or hydrocarbon/surfactant systems including glycol ethers, glycol ether acetates, esters, pyrollidone, and terpenes; and azeotropic and nonazeotropic mixtures. Most CFC-113 replacement efforts are targeted toward solvent cleaning of metal or electronic parts with little emphasis on drycleaning applications.

Relevant to LADDS solvent requirements:

- HCFCs now available commercially appear to most closely meet the specified Natick solvent requirements although HCFCs can only be regarded as a temporary solution because of their own phase-out schedule. HCFC-225, HCFC-141b, and HCFC-123 are believed to provide the best potential for success as "drop-in" replacements for CFC-113 in the short term.

- For traditional commercial drycleaning applications, perchloroethylene or high boiling hydrocarbons are considered the best commercially available alternatives at present, with HCFCs considered as interim alternatives. Perchloroethylene or high boiling hydrocarbons, however, do not meet the LADDS requirement for a low boiling, low heat of vaporization solvent. Hydrocarbon solvents also do not meet the requirement for nonflammability. Hydrocarbon solvents, however, are considered one of the best long-term, environmentally acceptable alternatives in some countries because they do not contain halogens.

- Some HFCs may be suitable as LADDS alternative solvents; however, only limited information on these compounds is now available. The solvating and cleaning properties of these fluids have not been fully evaluated. Also, the toxicological properties have not been tested. Some experimental work would be required to evaluate their feasibility as cleaning fluids both alone and in mixtures. A limited evaluation would be required to assess the feasibility of selected fluorinated ethers and alcohols, which are in the early stages of development.

- FCs are poor solvents and do not mix well with other HFCs and HCFCs. They do not appear to be suitable as a LADDS drycleaning fluid. However, FCs may be useful as additives to stabilize mixtures, balance solvent aggressiveness, or reduce flammability.

- Other solvents either commercially available or under development meet many of the LADDS requirements for physical properties but are not acceptable because they are flammable or combustible. Also, the effects of these solvents on various materials, including fabrics and finishes are not well documented.

- Several technical approaches and/or equipment are being pursued to improve suitability of some flammable or potentially toxic solvents (e.g., non-flammable vapor "blankets" or explosion proof cleaning systems to enable safe use of flammable solvents, low emission equipment to reduce worker exposures below permissible exposure limits.)

- Aqueous cleaning systems have been developed and are gaining greater acceptance for metal, electronics, and precision cleaning applications. The use of aqueous cleaners would require modifications to the current prototype design.

8.2 RECOMMENDATIONS

Based on the results of this study, the following recommendations are offered for consideration:

1. A thorough systems analysis of the LADDS requirements should be undertaken in light of recent regulatory changes. The analysis should include use requirements/frequency, location of use, types of textiles to be processed, skill of potential operators, etc. The system energy consumption limitations, and solvent toxicity and flammability requirements should be more specifically defined.

2. An evaluation of the present prototype or future LADDS design should be carried out to ensure that the unit can be readily modified, or adapted for use with a variety of solvents, and possibly solvent mixtures. Through such an effort, Natick will be better positioned to respond to future developments in solvent technology and increasingly restrictive national and multinational regulations.

3. The LADDS design should be reviewed to ensure that all materials of construction are compatible with the solvent alternatives in Section 7. One could speculate that future LADDS use scenarios might involve the specification of more than one solvent type. Such flexibility should be anticipated in the LADDS design.

4. The recommended substitute at present is HCFC-225 and only if its commercial availability continues until the presently proposed phaseout date of year 2005. The overall availability of LADDS alternative solvents should continue to be monitored, particularly as the EPA issues its CFC alternatives acceptability rules under the SNAP program in November 1992.

5. The feasibility of perchloroethylene as a drycleaning solvent in future LADDS designs should be explored.

6. The feasibility of aqueous-based systems as the cleaning solvent in future LADDS designs should be explored.

In general, the future LADDS design should be versatile so that it can be readily modified and adapted to meet changing operating requirements as solvent acceptability, availability, and regulations continue to change in the future.

This document reports research undertaken at the US Army Natick Research, Development and Engineering Center and has been assigned No. NATICK/TR-93/003 in the series of reports approved for publication.

APPENDIX A

INFORMATION SOURCE PROFILES

Type: Equipment Manufacturer

Name:	AGFA-Gevaert, Inc.
Address:	100 Challenger Road Ridgefield Park, New Jersey 07660
Contact:	Mr. William Bossman, Manager for Environmental Concerns
Phone No.:	(800) 631-0187
FAX No.:	
Description:	AGFA-Gevaert is a manufacturer of photographic materials and systems.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Mr. Bossman secretary indicated that Agfa-Gevaert has nothing to do with CFC's. We also contacted Agfa-Gevaert staff at several other locations -- none of which were familiar with any efforts concerning CFC's.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples

*D=Developed or developing, E=Evaluating, U=Using

Type: Chemical Producer

Name:	Akzo Chemicals International bv
Address:	Stationsplein 4 P.O. Box 247 3800 AE Amersfoort The Netherlands
Contact:	Mr. H. Jaspers, Manager Research and Business Development
Phone No.:	31-33-67 63 15
FAX No.:	31-33-67 61 50
Description:	Akzo is a major manufacturer of chemicals and solvents. Akzo is actively involved in related professional organizations and is a member of the Alternative Fluorocarbons Environmental Acceptability Study.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Mr. Jaspers believes that HCFC-225 is currently the best (and only) liquid/solvent alternative to CFC-113. At this time, they are marketing the product Demeon®225 CA/CB, which is a 50/50 blend of the CA and CB isomers. Because of its availability, much of their research has involved this blend. However, in less extensive testing, they have not observed significant performance differences with other isomers, such as the pure CB isomer. Akzo is also initiating a two-year project in conjunction with the Applied Research Institute (government sponsored organization), a dry-cleaner, and a machine builder, to study alternative methods/materials for dry-cleaning and mechanical cleaning of small parts.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples
D	Demeon® 225 CA/CB (HCFC-225 ca/cb)	Mixture	Y	Y

*D=Developed or developing, E=Evaluating, U=Using

Type: Chemical Producer

Name:	Allied-Signal Inc.
Address:	Engineered Solvent Systems P.O. Box 1139R Morristown, NJ 07962-1139 Genesolv/Baron-Blakeslee 2001 North Janice Avenue Melrose Park, IL 60160
Contact:	Mr. Kevin P. Murphy Dr. Kirk Bonner
Phone No.:	800-922-0964 708-450-3880
FAX No.:	201-455-2745 708-450-3895
Description:	Allied-Signal is a major producer of industrial chemicals, solvents, and polymers. Member of the UNEP Solvents, Coatings, and Adhesives Technical Options Committee; the Alternative Fluorocarbons Environmental Acceptability Study; and Program for Alternative Fluorocarbon Testing.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Allied-Signal now sells a series of solvents/mixtures by the tradename Genesolv that are based on HCFC-141b or mixtures of HCFC-141b and HCFC-123 as CFC-113 replacements. Although HCFC-141b has a lower boiling solvent than desired for LADDS use, Allied reports they are currently testing HCFC-141b in a commericial dry cleaning application (field testing in progress using Cleanline 30 lb. machine.) Allied reports that the results to date are good and that only modifications to the machine were regarding gasket materials. Questions remain, however, regarding environmental acceptability of HCF-141b (ODP=0.15) and its potential flammability (no flash point but vapor flammability limits of 7.6-17.7%). Allied also reports that they are committed to cease CFC production in 1995 and to accelerate development of "third-generation", non-ozone depleting solvents (no details) for commercialization in the 1995-1997 time frame.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples
D	Genesolv 2000 (HCFC-141b)	1717-00-6	Y	Y
D	Genesolv 2010 (HCFC-141b mixture)	Mixture	Y	Y
D	Genesolv 2020 (HCFC-141b/HCFC-123 mix)	Mixture	Y	Y

*D=Developed or developing, E=Evaluating, U=Using

Type: Association/Research Institute

Name:	All Japan Laundry & Drycleaning Association
Address:	472 Akiba-cho Totsuka-ku, Yokohama-shi Kanagawa-ken 245 Japan
Contact:	Mr. Shigeru Dejima
Phone No.:	81 45 811-3639
FAX No.:	81 45 812-5176
Description:	Japanese trade association addressing laundry and dry cleaning issues for member companies. Undertakes some solvents, cleaning performance and equipment design research through its Fabricare Research Center. Member of the International Drycleaning Research Committee and the Japanese ICOLP (JCOLP).
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	In the paper "Measures for Freon, etc. in Dry-Cleaning Industry in Japan" by the Fabricare Research Center of the All Japan Laundry & Dry-Cleaning Association, the four primary dry-cleaning solvents now being used in Japan are summarized. The four primary materials, (CFC-113, methylchloroform, perchloroethylene, and petroleum solvents) are presented as having significant drawbacks. The first three materials because of environmental concerns, and the fourth due to flammability. They add that no suitable replacement materials for CFC-113 are currently available, and that HCFCs 123, 141b, 225ca, and 225cb appear to be the most likely alternatives at this time.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples
E	HCFC-123	306-83-2	Y	
E	HCFC-141b		Y	
E	HCFC-225 cb		Y	
E	HCFC-225 ca		Y	

*D=Developed or developing, E=Evaluating, U=Using

Type: Association/Research Institute

Name:	Alternative Fluorocarbons Environmental Acceptability Study (AFEAS)
Address:	
Contact:	c/o Anthony Vogelsberg (DuPont Freon Products Division, Wilmington DE), AFEAS Representative
Phone No.:	302-999-5072
FAX No.:	302-999-5340
Description:	AFEAS was founded by a group of alternative fluorocarbon producers to evaluate the environmental impact of various CFC alternative technologies relative to current CFC compounds. AFEAS member companies include Akzo Chemicals, Allied-Signal, Asahi Glass, Elf Atochem, Daikin Industries, DuPont, Hoechst Celanese, ICI, LaRoche Chemicals, Montefluous, and Rhone Poulenc Chemicals.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	A recent program was undertaken, co-funded by AFEAS and DOE, to assess the overall contributions of CFC alternatives to global warming using a systems approach. The study evaluated the direct contribution of greenhouse gases used by the technology/process, and the indirect contribution of the carbon dioxide emissions resulting from the energy required to run the technology/process over its normal system life. Results showed that HCFC and HFC systems contributed less to global warming than other non-fluorocarbon alternatives in energy intensive applications such as refrigeration, air conditioning, and insulation. For solvent cleaning technologies, however, clear differences in global warming impact were not found among fluorocarbon and non-fluorocarbon options now available.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples

*D=Developed or developing, E=Evaluating, U=Using

Type: Equipment Manufacturer

Name:	American Telephone & Telegraph/Bell Laboratories
Address:	Bell Laboratories P.O. Box 900 Princeton, NJ 08540
Contact:	Dr. Leslie Guth William O. Gillum
Phone No.:	609-639-3040 609-639-2548
FAX No.:	609-639-2835
Description:	Major producer of electronic and communications equipment. Member of International Cooperative for Ozone Layer Protection (ICOLP) and UNEP Solvents, Coatings, and Adhesives Technical Options Committee.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	AT&T is committed to eliminating all CFC emissions by end of 1994. Efforts have been ongoing to evaluate CFC-113 alternatives for solvent cleaning applications. Several alternative cleaners have been evaluated including aqueous cleaners, esters, hydrocarbons, and terpenes. Techniques have also been developed to quantify cleaning effectives in precision cleaning applications, particularly regarding surface cleanliness. To date, a d-limonene/surfactant system (Bioact EC-7) and an aliphatic ester mixture has shown excellent results and are undergoing production trials using semi-aqueous cleaning process equipment.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples
E	Aliphatic ester mixture	Mixture	Y	Y
E	d/Limonene/surfactant (Bioact EC7)	Mixture	Y	Y

*D=Developing, E=Evaluating, U=Using

Type: Chemical Producer

Name:	Arakawa Chemical (USA), Inc.
Address:	625 North Michigan Avenue Suite 1700 Chicago, IL 60611
Contact:	Mr. Nick Honoki
Phone No.:	312-642-1750
FAX No.:	312-642-0089
Description:	Manufacturer of terpene-based solvents.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Arakawa produces a line of terpene-based solvents, tradename Pine-Alpha. They believe that Pine-Alpha ST-100S has strong potential as a replacements for CFC-113. This material is considered non-hazardous, non-flammmable, and water soluble. In addition, Arakawa has developed a process known as the Pine-Alpha Cleaning System (PAC). The system is comprised of a Pine-Alpha Cleaning machine, a monitoring sensor, and waste water treatment equipment. Arakawa claims that use of the Pine-Alpha ST-100S in the PAC system produces an economical, safe process with high cleaning power and which has been accepted with high regard by many Japanese electronics manufacturers. Chemical effects on plastics, elastomers, and metals has been found to be minimal.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples
D	Pime-Alpha ST-100S (Terpene)		Y	Y

*D=Developed or developing, E=Evaluating, U=Using

Type: Chemical Producer

Name:	Asahi Glass Company, Ltd.	
Address:	Hazawa-cho, Kanagawa-Ku Yokohoma City 221 Japan	Asahi Glass America, Inc. 1185 Avenue of the Americas 30th Floor New York, New York 10036
Contact:	Dr. Masaaki Yamabe	Mr. Shunuchi Samejima
Phone No.:	011-81-45-334-6111	212-764-3155
FAX No.:	011-81-45-334-6187	212-764-3384
Description:	Major manufacturer of chemicals and solvents, particularly HCFCs and HFCs. Actively involved in the UNEP Solvents, Coatings, and Adhesives Technical Options Committee; the Alternative Fluorocarbons Enivronmental Acceptability Study (AFEAS); and the Program for Alternative Fluorocarbon Testing (PAFT).	
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Asahi produces Asahiklin AK-225(cb), which is the cb isomer of HCFC-225. Asahi believes that currently this is the best alternative material to CFC-113, as its properties most closely match those of CFC-113 and its ozone depletion potential is about 1/20th of CFC-113. Asahi has selected this particular 225 isomer combination because of ease of production and these isomers have the appropriate stability. Asahi also manufactures numerous other HCFCs, HFCs, and CFCs, including 134a and 142b. They are currently developing a new HCFC material which should be commercialized in 1994 or 1995. Other research efforts are also being undertaken.	

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples
D	Asahiklin AK-225 cb (HCFC-225 cb)		Y	Y
D	Asahiklin AK-141b (HCFC-141b)		Y	Y
D	Asahiklin AK-123 (HCFC-123)	306-83-2	Y	Y
D	Asahiklin AK-152a (HCFC-152a)		Y	Y

*D=Developed or developing, E=Evaluating, U=Using

Type: Chemical Producer

Name:	Ashland Chemical, Inc.
Address:	Industrial Chemicals & Solvents Division P.O. Box 2219 Columbus, OH 43216
Contact:	Mr. J. H. Sweet
Phone No.:	614-889-3806
FAX No.:	614-889-4294
Description:	Major producer of chemicals, solvents, and polymers.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Ashland has been involved in solvent development and evaluation efforts for various cleaning applications, including textile drycleaning, although they are not specifically targetting replacements that match CFC-113 physical properties.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples

*D=Developed or developing, E=Evaluating, U=Using

Type: Chemical Producer

Name:	Bayer AG
Address:	D-5090 Leverkusen Bayerwerk Germany
Contact:	Customer Service
Phone No.:	011 49 214 30 33 80
FAX No.:	
Description:	Major manufacturer of chemicals, solvents, and consumer products.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Stated that they do not manufacture CFC's or CFC replacements, nor are they involved in any research efforts. Also called Mobay Corporation, Pittsburgh, Pennsylvania (412-777-2000). They repeated what the German office said and suggested we contact a company called Detrex Corporation.

CFC-113 Replacements or Alternatives:

D/ E/U*	**Name**	**CAS No.**	**Availability**	
			Comm.	**Samples**

*D=Developed or developing, E=Evaluating, U=Using

Type: Equipment Manufacturer

Name:	British Aerospace Defense Ltd., Dynamics Division
Address:	P.O. Box 19 (PB 221) 6 Hills Way Stevenage, Hertfordshire SG1 2DA Great Britain
Contact:	Brian Baxter
Phone No.:	011 44 438 753 222
FAX No.:	011 44 438 756 100
Description:	British Aerospace Dynamics is a manufacturer of aircraft and uses CFC-113 in various cleaning applications. Brian Baxter is an active participant on the UNEP Solvents, Coatings, and Adhesives Technical Options Committee.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	British Aerospace has developed a process that uses isopropanol under a perfluorocarbon vapor blanket in order to reduce and control the overall flammability. Baxter says the process works quite effectively from the cleaning, drying, toxicity, and flammability standpoints, although the necessity of using the perfluorocarbon blanket is a disadvantage. The system is being evaluated by General Electric in Schenectady, New York (contact John Verbilkey). They are using Ultrasonic Power Services of Chapel-Enlefrith, Stockport SK12612D to market the cleaning system in the United States. The perfluorocarbons are being supplied by the ISC Division of Rhone-Poulenc and 3M. Overall, he felt the status of CFC-113 alternative materials was "not very good".

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples
E	Isopropanol	67-63-0	Y	Y

*D=Developed or developing, E=Evaluating, U=Using

Type: Chemical Producer

Name:	British Petroleum Limited
Address:	Technical Service and Development Saltend, Hull HU12 8DS Great Britain
Contact:	Dr. Neil Poole, Research Director
Phone No.:	011-44-482-892 356
FAX No.:	011-44-482-892 828
Description:	Manufacturer of chemicals and solvents. Actively involved in related professional organizations.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	British Petroleum is developing a line of products called Prozone® to serve as replacements for CFC-113. These materials are mixtures of various glycol ethers. Because of licensing (tradename) concerns, only limited product information is available in the United States now regarding Prozone materials. Poole stated that their efforts have been focused toward metal cleaning and printed circuit board applications. He added that because most of these materials are hydrophillic, they will tend to swell fibers and may not be appropriate for fabric cleaning applications. They also have high boiling points.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples
D	Glycol ether MP	107-98-2	N	N
D	Glycol ether ester MPA	108-65-6	N	N

*D=Developed or developing, E=Evaluating, U=Using

Type: Chemical Producer

Name:	Bush Boake Allen, Ltd.
Address:	Blackhorse Lane Walthamstow E17 5QP London Great Britain
Contact:	Ray Ford
Phone No.:	011 44 81 531-4211
FAX No.:	
Description:	Bush Boake Allen chemically modifies the terpene-based raw materials supplied by its parent company, Union Camp, to produce a line of high performance terpene solvents.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Ford suggested that I contact their U.S. affiliate, Union Camp -- Wayne Cristman (904) 783-2180. Cristman state that Union Camp/Bush Boake Allen has a series of terpene-based (turpentine by-products) solvents which they are modifying to function as cleaning solvents. Modification is typically accomplished by addition to proprietary alcohols to produce fast-drying solvents which leave no residue. At present they have 6 or 7 solvents available. The major drawback of these solvents is that they do not have a flash point over 140°F. The materials represent a very new (8 or 9 months) business area and feedback on their effectiveness is very limited, but are viewed as questionable for fabric cleaning.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples
D	BBA Solvent E202 (Terpene)		Y	Y
D	BBA Solvent K401 (Terpene)		Y	Y

*D=Developed or developing, E=Evaluating, U=Using

Type: Chemical Producer

Name:	Central Glass
Address:	3-7-1, Kanda-Nishikicho Chiyoda-ku Tokyo 101 Japan
Contact:	
Phone No.:	011-03-3259-7111
FAX No.:	
Description:	Chemical manufacturer.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	It is believed that Central Glass is manufacturing HCFC-141b and perhaps other HCFCs. However, efforts to discuss their activities with the appropriate representative have been unsuccessful.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples

*D=Developed or developing, E=Evaluating, U=Using

Type: Chemical Producer

Name:	Chimie Innovations et Technologies (CIT)
Address:	France
Contact:	
Phone No.:	
FAX No.:	
Description:	Manufacturer of chemicals and solvents.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Reportedly, CIT manufactures a product called Biosane, which has potential as a CFC replacement material. Efforts to identify an appropriate phone listing and address were unsuccessful.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples

*D=Developed or developing, E=Evaluating, U=Using

Type: Association/Research Institute

Name:	Cleaning Techniques Research Institute (IRTNO)
Address:	P.O. Box 6062 2600 JA Delft Netherlands
Contact:	Mr. Wagl Den Otter
Phone No.:	011-31-015-696933
FAX No.:	011-31-015-560258
Description:	Cleaning Techniques Research Institute (IRTNO) is a research organization which is conducting considerable work in the area of alternative cleaning materials/methods. IRTNO is a member of the International Drycleaning Research Committee.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Mr. Den Otter indicated that HCFC-225 (Demeon 225 CA/CB manufactured by Akzo) is the most promising material evaluated based on performance and its low ODP. He stated that several new detergent systems exist which should be evaluated. IRTNO has also evaluated various blends of HCFC's 123, 141, and 142 with minimal success. Another material which has been evaluated is Genosolve (Allied Signal), but was found to be unacceptable because of its high ODP. On the equipment side, Mr. Den Otter stated that developments are required, as the majority of the cleaning machines allow a 5-6% loss of cleaning materials. A 3% loss is deemed acceptable.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples
E	HCFC-225 (Demeon 225 CA/CB by Akzo)		Y	Y

*D=Developing, E=Evaluating, U=Using

Type: Association/Research Institute

Name:	Clemson University
Address:	Department of Chemistry Clemson, South Carolina 29634-1905
Contact:	Dr. Darryl D. DesMarteau Dr. Adolph L Beyerlein
Phone No.:	803-656-4705
FAX No.:	
Description:	University chemistry department.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Recently completed a program (December 1991) funded jointly by EPA and EPRI to synthesize and measure/estimate the physical properties of a series of fluorinated propanes and butanes as potential CFC replacements, primarily for refrigerant applications. While the research emphasis was on compounds with much lower boiling points than CFC-113, some of compounds synthesized may be suitable as CFC-113 replacements. Examples include HCFC-225ba, HCFC-225da, HCFC-244ca, octafluorobutane (HFC-338), hexafluorocyclobutane (C-326d). Additional research to better characterize these compounds is necessary. Facilities and personnel at Clemson would available for further compound synthesis and characterization work, under contract, if the Army identified such a need.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples
D	HCFC-225ba and HCFC-225da		N	N
D	HCFC-244ca (Chlorotetrafluoropropane)		N	N
D	HFC-338 (Octafluorobutane)		N	N
D	HFC-326d (Hexafluorocyclobutane)		N	N

*D=Developing, E=Evaluating, U=Using

Type: Equipment Manufacturer

Name:	Columbia Machine Corporation
Address:	1540-J Caton Center Drive Baltimore, Maryland 21227
Contact:	Robert Franklin, President
Phone No.:	800-356-5634
FAX No.:	301-247-7759
Description:	Manufacturer of commercial dry cleaning equipment.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	None, primarily manufacture perchloroethylene-based drycleaning machines although they are available to participate in evaluations of alternative solvents and drycleaning equipment designs.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples

*D=Developing, E=Evaluating, U=Using

Type: Association/Research Institute

Name:	CTTN - IREN
Address:	BP 41, Avenue Guy de Collonque 69131 Ecully Cedex France
Contact:	Mr. Marc Eglizeau
Phone No.:	011 33 78 33 08 61
FAX No.:	011 33 78 43 39 6618
Description:	CTTN-IREN is a French association/research institute providing information and services regarding laundry and dry cleaning technology and equipment. Mr. Eglizeau is the 1992 Chairman of the International Drycleaning Research Committee.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	CTTN-IREN is not now undertaking any research regarding CFC-113 solvent replacements for the dry cleaning industry, although they do provide some information regarding regulations and activities in this area.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples

*D=Developed or developing, E=Evaluating, U=Using

Type: Chemical Producer

Name:	Daikin Industries, Ltd.
Address:	2-4-12, Nakazaki-Nishi Kita-ku Osaka 530 Japan
Contact:	
Phone No.:	06-373-1201
FAX No.:	
Description:	Major Japanese chemical and solvent manufacturer. Daiken is a member of the Alternative Fluorocarbons Environmental Acceptability Study and the Program for Alternative Fluorocarbon Testing.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	It is believed that Daikin produces solvents such as HCFC-142b and Daiflon 11RM. However, efforts to discuss their position with the appropriate representative have been unsuccessful.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples

*D=Developed or developing, E=Evaluating, U=Using

Type: Association/Research Institute

Name:	Danish Clothing and Textile Institute
Address:	Gregersensvej 5 P.O. Box 80 DK-2630 Taastrup Denmark
Contact:	Mr. John Hansen
Phone No.:	011 452 99 88 22
FAX No.:	011 45 4252 2444
Description:	The Danish Clothing and Textile Institute is a member of the International Drycleaning Research Committee.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Information requested from this source was not received prior to completion of the task. Follow-up requests were unsuccessful.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples

*D=Developed or developing, E=Evaluating, U=Using

Type: Equipment Manufacturer

Name:	Detrex Corporation
Address:	P.O. Box 569 401 Emmett Drive Bowling Green, KY 42102
Contact:	Mr. Wayne Mouser
Phone No.:	502-782-1511
FAX No.:	502-781-3425
Description:	Manufacturer of aqueous and semi-aqueous cleaning equipment.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Detrex focuses on developing semi-aqueous cleaning equipment and automated cleaning systems for production lines. Recent efforts have involved developing inline cleaning systems for high volume production facilities using semi-aqueous cleaners (Petroferm EC-7R, Dupont's Axarel 38, others).

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples

*D=Developed or developing, E=Evaluating, U=Using

Type: Equipment Manufacturer

Name:	Digital Equipment Corporation
Address:	274 Cedar Hill Road Marlboro, MA 01752
Contact:	Mr. Leo Lambert
Phone No.:	508-467-7332
FAX No.:	508-467-7588
Description:	Major producer of computer and electronic communications equipment. Member of International Cooperative for Ozone Layer Protection (ICOLP) and UNEP Solvents, Coatings, and Adhesives, Technical Options Committee.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Digital previously used CFC-113 extensively for precision cleaning operations. Their initial goal was to phaseout CFC use by 1995, however, they are now targeting 1991/1992 for complete elimination. In addition to initial CFC use reductions, Digital undertook an extensive feasibility study to evaluate organic, semi-aqueous, and aqueous cleaning systems for their precision cleaning applications. Based on that study, Digital has now implemented an aqueous cleaning system (with synthetic detergent blend of nonionic and anionic surfactants and additives) using ultrasonic immersion washing, multi-stage rinsing, and drying by mechanical dewatering using high velocity/high volume filtered air followed by evaporative drying.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples
E/U	Aqueous cleaning system	NA		

*D=Developing, E=Evaluating, U=Using

Type: Chemical Producer

Name:	Dow Chemical Company
Address:	Chemicals & Metals Department 2020 Dow Center Midland, MI 48674 Advanced Cleaning Systems Midland, MI 48674
Contact:	Mr. James A. Mertens; Mr. Douglas Crouch
Phone No.:	517-636-8325; 517-636-5082
FAX No.:	517-636-9899
Description:	Dow Chemical is a major producer of industrial chemicals, solvents, and polymers. Dow is a member of the UNEP Solvents, Coatings and Adhesives Technical Options Committee and is involved in the committee's technical assessment activities regarding metal cleaning, precision cleaning, adhesives, coatings and inks, and aerosols.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Dow is approaching CFC-113 replacement research from a cleaning systems viewpoint that considers solvent/equipment performance and environmental acceptability. Developed Dowinal (XUS-11268), a semi-aqueous cleaner based on propylene glycol ether technology. Dowinal is halogen free, has low vapor pressure, and high flash point. It is claimed to be biodegradable under certain laboratory conditions. Dow also continues to be a major producer of chlorinated solvents for solvent cleaning, including drycleaning, applications.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples
D	Chlorinated solvents		Y	
D	Propylene glycol ethers		Y	

*D=Developed or developing, E=Evaluating, U=Using

Type: Chemical Producer

Name:	E.I. duPont de Nemours and Company, Inc. (DuPont)
Address:	Chemicals and Pigments Division Wilmington, Delaware 19880-0402
Contact:	Mr. Herb Fritz
Phone No.:	302-248-5017
FAX No.:	302-248-5026
Description:	A major producer of industrial chemicals, solvents, and plastics. They manufacture the Freons (CFCs) which are used as cleaners, aerosol propellants, refrigerants, and foam blowing agents and are scheduled for phaseout in 1995. Dupont is a member of the UNEP Solvents, Coatings, and Adhesives Technical Options Committee; the Alternative Fluorocarbons Environmental Acceptability Study; and the Program for Alternative Fluorocarbon Testing.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Du Pont has significantly reduced efforts to develop CFC substitutes mainly because of toxicity and regulatory issues. HCFC-225 and perfluorodimethylcyclobutane are no longer being developed by Du Pont as substitutes for CFC-113. At present, the only HCFC substitute for CFC-113 available from DuPont is HCFC-123. Users must certify that their application will not exceed Du Pont's allowed exposure limits (AEL or TLV value). For metal cleaning applications, DuPont has developed a line of high purity hydrocarbons solvents (tradename Axarel) as CFC-113 replacements. These hydrocarbons, however, have boiling points >300°F and are not expected to be suitable for drycleaning applications.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples
D	HCFC-123	306-83-2	Y	Y
D	Axarel 38, 52, 6100, and 9100 (hydrocarbon-based formulations)	NA	Y	Y

*D=Developed or developing, E=Evaluating, U=Using

Type: Equipment Manufacturer

Name:	Ebara Corporation
Address:	11-1, Hameda-Asahicho Ohta-ku Tokyo Japan
Contact:	Mr. A. Hashimoto, Manager, Corporate Planning Department
Phone No.:	03 3743 6111
FAX No.:	81 33 745 3010
Description:	Manufacturer of refrigeration equipment.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Mr. Hashimoto indicated that Ebara does not have alternative materials/equipment for CFC-113.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples

*D=Developed or developing, E=Evaluating, U=Using

Type: Association/Research Institute

Name:	Electric Power Research Institute (EPRI)	
Address:	3412 Hillview Avenue Palo Alto, CA 94303	
Contact:	Mr. Powell Joyner	Mr. Wayne Krill
Phone No.:	415-855-2580	415-855-2000
FAX No.:	415-855-2954	415-855-2954
Description:	EPRI is an independent, non-profit research and development organization that manages R&D on behalf of the U.S. electric utility industry and public to advance capabilities in electric power generation, delivery, and use.	
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Two programs have been recently completed (December 1991 and February 1992) to synthesize and measure/estimate the physical properties of two classes of compounds as potential CFC replacements, primarily for refrigerant applications. This work was carried out at Clemson University and the University of Tennessee and was funded jointly by the EPRI and the EPA Air and Energy Engineering Research Laboratory. Efforts at Clemson University focussed on fluorinated propanes and butanes, while the efforts at University of Tennessee focussed on fluorinated ethers. While the research emphasis was on compounds with much lower boiling points than CFC-113, some of compounds synthesized may be suitable as CFC-113 replacements. Additional research to better characterize these compounds would be necessary.	

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples
D/E	Fluorinated butanes and propanes	NA	N	N
D/E	Fluorinated ethers	NA	N	N

*D=Developing, E=Evaluating, U=Using

Type: Chemical Producer

Name:	Elf Atochem
Address:	Elf Atochem North America, Inc. Three Parkway Philadelphia, Pennsylvania 19102
Contact:	Lee Chambers, Marketing Manager - Fluorochemicals
Phone No.:	(215) 587-7000
FAX No.:	
Description:	Major manufacturer of chemicals and solvents. Member of the UNEP Solvents, Coatings, and Adhesives Technical Options Committee; the Alternative Fluorocarbon Environmental Acceptability Study; and the Program for Alternative Fluorocarbons Testing.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Elf Atochem manufactures a line of HCFC's (141b, 134a, 142b, 113sv, etc.) called Forane® which are used in various applications. Although most of their efforts have been in the areas of metal cleaning and printed circuit board applications, Mr. Chambers' believes that Forane 141b is currently the most appropriate alternative for CFC-113. Mr. Chambers added that Elf Atochem is developing other materials, but most of these projects are new and the work is confidential.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples
D	HCFC-113 sv		Y	Y
D	HCFC-141b	1717-00-6	Y	Y
D	HCFC-142b		Y	Y
D	HCFC-134a		Y	Y

*D=Developed or developing, E=Evaluating, U=Using

Type: Chemical Producer

Name:	Envirosolv Inc.	
Address:	1840 Southside Boulevard Jacksonville, FL 32216	
Contact:	Mr. Steven M. Collier	Mr. Robert L. Klopfenstein
Phone No.:	508-653-7655	904-724-1990
FAX No.:	508-653-7731	904-724-2508
Description:	Producer of solvents and solvent mixtures for industrial process cleaning applications with a focus on terpene-based products.	
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Envirosolv produces RE-ENTRY line of terpene-based cleaning formulations for use in semi-aqueous cleaning processes.	

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples
D	RE-ENTRY KNI Solvent - 2000	NA	Y	Y
D	RE-ENTRY ES Solvent Degreaser	NA	Y	Y
D	RE-ENTRY RFS Solvent - 2000	NA	Y	Y

*D=Developed or developing, E=Evaluating, U=Using

Type: Association/Research Institute

Name:	European Committee of Laundry and Dry Cleaning
Address:	18A Northampton Square London EC1V OEJ Great Britain
Contact:	
Phone No.:	011 44 71 253-7132
FAX No.:	
Description:	Professional trade association
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Unable to contact with above telephone listing. Efforts to find an alternative phone listing were unsuccessful. Also, attempted to contact H. Graham King & Co. (company associated with the above organization), however, no listing could be found.

CFC-113 Replacements or Alternatives:

D/ E/U*	**Name**	**CAS No.**	**Availability**	
			Comm.	**Samples**

*D=Developed or developing, E=Evaluating, U=Using

Type: Association/Research Institute

Name:	European Fluorocarbon Technical Committee
Address:	4 Avenue E. van Nieuwenhuyse B-1160 Brussels Belgium
Contact:	
Phone No.:	011 33 2 6767211
FAX No.:	
Description:	Professional trade association
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Above phone listing was "no longer in service." Efforts to identify an alternative phone listing were unsuccessful.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples

*D=Developed or developing, E=Evaluating, U=Using

Type: Association/Reasearch Institute

Name:	European Laundry and Dry Cleaning Machinery Manufacturers Org.
Address:	c/o Italian Association of Textile Machinery Producers (ACIMIT) via Tevere 1 20123 Milan, Italy
Contact:	Dr. Giancarlo Monti, Secretariat
Phone No.:	011-39 2 49 88 125
FAX No.:	011-39 2 48 00 83 42
Description:	ELMO is an association of laundry and dry cleaning machinery manufacturers that addresses economic and technical problems associated with industry developments, customs, and international standardization and assists in information exchange. Also coordinates exhibitions of laundry and dry cleaning equipment. ELMO members include associations in Belgium, France, Germany, Great Britain, Spain, Sweden, and Switzerland.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	ELMO is mainly involved in efforts to disseminate information regarding drycleaning equipment and technology issues. They have not sponsored any research specifically regarding alternative solvents but are aware of activities by some member companies to develop bivalent machines that can use two types of solvents (unsuccessful) or that substitute HCFCs or HFCs for CFC-113. Dr. Monti characterized drycleaning solvent use in Italy as: 90-93% perchloroethylene, 5-8% CFC-113, < 1% trichloroethylene, and < 1% 1,1,1-trichloroethane.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples

*D=Developed or developing, E=Evaluating, U=Using

Type: Chemical Producer

Name:	Exxon Chemical Company
Address:	P.O. Box 3273 Houston, TX 77001 Exxon Chemical Canada P.O. Box 4029, Station A Toronto, Ontario M5W 1K3 Canada
Contact:	Dr. Peter G. Miasek
Phone No.:	800-231-6633 416-733-5310
FAX No.:	
Description:	Major manufacturer of chemicals, solvents, and polymers with emphasis on hydrocarbon-based products.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Exxon has developed several non-aqueous hydrocarbon based systems as CFC-113 replacements for precision and metal cleaning solvents. The products include the ACTREL® line of paraffinic hydrocarbons (flammable) and the EXXATE® line of aliphatic acetate ester blends; both of which are high-boiling compounds. Exxon has worked with Safety-Kleen to develop cleaning system equipment that is inherently safe regarding control of flammability and VOC emissions. Exxon also manufacturers a line of traditional hydrocarbon based drycleaning solvents (Isopar).

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples
D	Actrel (several)		Y	Y
D	Exxate 800/1000		Y	Y
D	Isopar		Y	Y

*D=Developed or developing, E=Evaluating, U=Using

Type: Association/Research Institute

Name:	Fabric Care Research Association
Address:	Forest House Laboratories Knaresborough Road Harrogate, North Yorkshire Great Britain HG2 7LZ
Contact:	Mr. Chris J. Tebbs Mr. Mike J. Palin
Phone No.:	011-44-423-885 977
FAX No.:	011-44-423-88-00-45
Description:	FCRA provides research and technical services for the laundering, dry cleaning, linen hire, and textile rental industries in Great Britian. Research involves washing and dry cleaning processing, the washability and dry cleanability of textiles and leathers, as well as surveys and troubleshooting projects within member plants to reduce costs and improve productivity. Founding members of the International Drycleaning Research Committee and the International Scientific and Technical Committee for Laundering.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	FCRA is not now undertaking any research regarding CFC-113 solvent alternative, but provides news letters and technical reports to disseminate information on CFC-113 replacement research and development activities worldwide. FCRA estimates that 25% of British drycleaners now use CFC-113, with most users looking to convert to perchloroethylene as equipment replacement is necessary. Current British exposure limits for perchloroethylene are 50 ppm (long term/8 hour) and 150 ppm (short term/10 minutes). FCRA does not anticipate much move toward hydrocarbon solvents because of flammability and regulatory restrictions.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples

*D=Developed or developing, E=Evaluating, U=Using

Type: Equipment Manufacturer

Name:	Grace Equipment Corporation
Address:	34 Washington Parkway P.O. Box 1000 Bethpage, New York 11714
Contact:	William A. Hayday, President
Phone No.:	516-822-9500
FAX No.:	516-433-3416
Description:	Manufacturer of commercial dry cleaning equipment.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	None, primarily manufacture perchloroethylene-based dry cleaning machines although they are available to participate in evaluations of alternative solvents and drycleaning equipment designs.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples

*D=Developed or developing, E=Evaluating, U=Using

Type: Chemical Producer

Name:	Halocarbon Products Corp.
Address:	887 Kinderkamack Road River Edge, New Jersey 07661
Contact:	Mr. Bernard Schitt, Assistant Sales Manager
Phone No.:	201-262-8899
FAX No.:	201-262-0019
Description:	Manufacturer of halogenated solvents and oils.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	They are currently producing trifluoroethanol and HCFC-123 which can be used in special mixtures and azeotropes for certain CFC-113 substitute applications.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples
D	HCFC-123	306-83-2	Y	Y
D	Trifluoroethanol		Y	Y

*D=Developing, E=Evaluating, U=Using

Type: Equipment Manufacturer

Name:	Hitachi Ltd.
Address:	New Marunouchi Building 5-1, Marunouchi 1 chome Chiyodaku, Tokyo 100 Japan
Contact:	Yoshiyuki Ishii, Senior Engineer
Phone No.:	81-3-3212-1111, Ext. 2722
FAX No.:	81-3-3212-3067
Description:	Chemical manufacturer; active in UNEP Solvents, Coatings, and Adhesives Technical Options Committee; and other CFC-related organizations.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	It does not appear that Hitachi has any alternative materials or processes for CFC-113. However, they do carefully monitor the CFC replacement situation -- most likely to remain cognizant of the premier materials for use in their operations. Mr. Ishii referred us to the All Japan Laundry and Dry-Cleaning Industry. Hitachi has experimented with two novel cleaning systems with some success. The first, UV/O_3 cleaning, produces ozone at a specific wavelength of light, and then decomposes organic materials at a higher light wavelength. The second uses CO_2 as a supercritical fluid to remove primarily organic materials.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples

*D=Developed or developing, E=Evaluating, U=Using

Type: Chemical Producer

Name:	Hoechst Celanese Corporation
Address:	Advanced Technology Group New Business Development 51 John F. Kennedy Parkway Short Hills, New Jersey 07078
Contact:	Mr. Gerard Rankin Mr. Zeigfried
Phone No.:	(201) 912-4986 011-49-069-305-6553
FAX No.:	
Description:	Manufacturer of chemicals, solvents, and polymers.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Mr. Rankin stated that Hoechst is involved in major development programs for the replacement of CFC's. However, they are not focusing on CFC-113. At this time, the only commercially-available material is HCFC 134a. We also spoke to a Mr. Zeigfried (011-49-069-305-6553) of their Frankfurt, Germany office. However, due to communication problems, we were referred to their United States office.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples

*D=Developed or developing, E=Evaluating, U=Using

Type: Association/Research Institute

Name:	Hohenstein Institute
Address:	D-7124 Bönnigheim Schloss Hohenstein Germany
Contact:	Ms. Petra Klein Mr. J. Kurz
Phone No.:	011 49 7143 27174
FAX No.:	011 49 7143 27151
Description:	Hohenstein Institute is a member of the International Drycleaning Research Committee.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Information requested from the source was not received prior to completion of this task.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples

*D=Developed or developing, E=Evaluating, U=Using

Type: Association/Research Institute

Name:	Höhere Bundes-Lehr u. Versuchsanstalt für Textilindustrie
Address:	1050 WIEN, Spengergasse 20 Austria
Contact:	Mr. H. Helmut
Phone No.:	011 438 284 128
FAX No.:	
Description:	Member of the International Drycleaning Research Committee.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	None. They primarily serve as an information dissemination group.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples

*D=Developed or developing, E=Evaluating, U=Using

Type: Equipment Manufacturer

Name:	HRPR Exports Limited
Address:	Unit 7, Merlin Center County Oak Way Crawley West Sussex RH10 1XX Great Britain
Contact:	Peter Gallows
Phone No.:	011-44-0656-66 38 49
FAX No.:	
Description:	Manufacturers of refrigeration equipment
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Reportedly, HRPR has a process for recycling/purifying CFC's and HCFC's. The technology utilizes a distillation process which was licensed by Akzo. Mr. Gallows failed to respond to any of our numerous messages.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples

*D=Developed or developing, E=Evaluating, U=Using

Type: Chemical Producer

Name:	Hurri Kleen Corporation
Address:	Subsidiary of Self Industries, Inc. 6000 Southern Industrial Drive Birmingham, AL 35235
Contact:	Mr. Tom Zingle Ms. Bobbie Pettit
Phone No.:	(205) 655-8808 (703) 764-0034
FAX No.:	(205) 655-5392 (703) 425-3537
Description:	Hurri-Kleen Corporation is a producer of aqueous cleaning chemicals.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Developed HURRI-SAFE® line of alkaline degreasers for general cleaning and degreasing of a broad range of cleaning surfaces as well as metal surface preparation processes. HURRI-SAFE degreasers are aqueous cleaners claimed to be non-flammable, non-toxic, and biodegradable.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples
D	Hurri-Safe Hot Immersion Degreaser	NA	Y	Y
D	Hurri-Safe Special Formula	NA	Y	Y
D	Hurri-Safe Heavy Duty Industrial Degreaser	NA	Y	Y
D	Hurri-Safe Formula #301 Degreaser	NA	Y	Y

*D=Developed or developing, E=Evaluating, U=Using

Type: Chemical Producer

Name:	Imperial Chemicals Industries (ICI)	
Address:	Imperial Chemical House Millbank, London SW1P 3JF Great Britain	Chemical & Polymers, Ltd. P.O. Box 19 Runcorn, Cheshire WA7 4LW Great Britain
Contact:	David Hey	Dr. Peter Johnson
Phone No.:	011 44 92 851-4444	011-44-92-851-2556
FAX No.:		011-44-92-858-0742
Description:	World's largest manufacturer of CFC-113. Actively involved in development of replacement materials, and committed to ceasing CFC production in 1995. Members of the UNEP Solvents, Coatings, and Adhesives Tehnical Options Committee; the Alternative Fluorocarbons Environmental Acceptability Study; and the Program for Alternative Fluorocarbon Testing.	
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	ICI is currently undertaking considerable research efforts to develop alternative solvents and expect to commercialize products by 1993. Hey suggested that fabric cleaning applications may be difficult for two reasons: (1) it is a low priority (low volume) application, so it receives little attention, and (2) compounds containing hydrogen are inappropriate for use with nuclear contaminants, which eliminates HCFC's. Hey believes the Army may need to make concessions in their requirements for an alternative material. They may have to pay a premium, or may need to accept lower performance. Possible alternative materials for the LADDS application are the perfluorocarbons produced by 3M. These materials contain no chlorine or hydrogen, but are expensive.	

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples

*D=Developed or developing, E=Evaluating, U=Using

Type: Association/Research Institute

Name:	Industry Cooperative for Ozone Layer Protection (ICOLP)
Address:	1440 New York Avenue, NW Suite 300 Washington, DC 20005
Contact:	Mr. Steven B. Hellem
Phone No.:	202-737-1419
FAX No.:	202-639-8685
Description:	ICOLP was formed by a group of industries to protect the ozone layer through coordinated efforts to exchange non-proprietary information on alternative technologies, substances, and processes to eliminate ozone-depleting solvents. At present, ICOLP has 17 corporate members as well as a number of industry association and government organization affiliates. ICOLP is working with the U.S. EPA to disseminate technical information on solvent alternatives and is working with the National Academy of Engineering to hold workshops to identify promising research directions. ICOLP also has developed and is now supporting OZONET, an alternative technologies electronic database.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	ICOLP itself does not undertake replacement/alternative solvent research, but actively seeks to disseminate research and development information from its member companies, affiliates, and other sources.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples

*D=Developed or developing, E=Evaluating, U=Using

Type: Association/Research Institute

Name:	International Drycleaning Research Committee (IDRC)
Address:	c/o CTTN-IREN BP41, Avenue Guy de Collongue 69131 Ecully Cedex France
Contact:	Mr. Marc Eglizeau
Phone No.:	011-33-78-33-08-61
FAX No.:	011-33-78-43-39-6618
Description:	IDRC is a group of 14 trade associations and research institutes that exchange information regarding drycleaning tehnology and equipment developments. Member organizations represent Austria, Denmark, Finland, France, Germany, Great Britain, Japan, The Netherlands, New Zealand, Sweden, Spain, and the United States. CTTN-IREN is the 1992 Committee Chairman, a position that rotates each year among the 14 members.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	IDRC has not, itself, sponsored any CFC-113 solvent replacement research but acts primarily to disseminate information provided by industry and other researchers regarding new technology developments and industry issues.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples

*D=Developed or developing, E=Evaluating, U=Using

Type: Association/Research Institute

Name:	International Fabricare Institute (IFI)	
Address:	12251 Tech Road Silver Spring, MD 20904	
Contact:	William E. Fisher	Betty Leppin
Phone No.:	301-622-4800	301-622-1900
FAX No.:	301-236-9320	
Description:	International association of retail and industrial drycleaners, hospital laundries, linen and drapery suppliers, machinery and supply manufacturers and distributors, and other drycleaning and laundry association. Member of International Drycleaning Research Committee.	
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	While IFI provides drycleaning consulting and testing services for member companies, they do not independently undertake drycleaning solvent performance research although they have done some work confidentially under contract. IFI tracks CFC-113 replacement solvent activities and provides information transfer through their many newsletters. However, because most of their members are perchloroethylene users, IFI tends to focus on issues related to perchloroethylene. For example, IFI assisted EPA in their development of recent guidelines requiring better solvent emissions control under the 1990 CAA/NESHAPS amendments.	

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples

*D=Developed or developing, E=Evaluating, U=Using

Type: Chemical Producer

Name:	ISP (formerly GAF Chemicals Corporation)
Address:	1361 Alps Road Wayne, NJ 07470
Contact:	Dr. Anthony Durante
Phone No.:	201-628-3110
FAX No.:	
Description:	ISP (International Specialty Products) is a specialty chemical producer and major producer of pyrrolidone-based products. In May 1991, ISP was formed as a new GAF subsidiary to operate the business and assets of what formerly was the GAF Chemicals Corporation.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	ISP markets N-methyl-2-pyrrolidone (commercial names M-Pyrol or NMP, or PartsPrep Degreaser) as a CFC-113 replacement for metal cleaning applications. N-methyl-2-pyrrolidone is miscible with water and many organic solvents and is claimed to have good solvating properties. ISP reports initial test results indicate that N-methyl-2-pyrrolidone is effective for metal cleaning for both spray wash and immersion tank cleaning processes, with a deionized water rinsing step. However, because of its high boiling point (395°F) and high heat of vaporization, this compound has not been considered for drycleaning-type applications. Also, n-methyl-2-pyrolidone is incompatible with several materials including PVC, viton fluoroelastomer, ABS, nitrile rubber, PET, and some acrylic polymers.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples
D	N-Methyl-2-pyrrolidone (M-Pyrol, NMP)		Y	Y

*D=Developed or developing, E=Evaluating, U=Using

Type: Association/Research Institute

Name:	Japan Association for Hygiene of Chlorinated Solvents
Address:	Hongoh-Wakai Building 40-17 Hongoh 2-chome Bunkyo-ku, Tokyo 113 Japan
Contact:	Mr. Hiroshi Kurita
Phone No.:	81 33 814-3411
FAX No.:	81 33 814-3413
Description:	Trade association
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Efforts to discuss their position with an appropriate representative have been unsuccessful.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples

*D=Developed or developing, E=Evaluating, U=Using

Type: Chemical Producer

Name:	Kanto Denka Kogyo Co., Ltd.
Address:	Tokio Kaijo Building Shinka 11th Floor 1-2-1, Marunouchi, Chiyoda-ku, Tokyo 100 Japan
Contact:	Mr. Shun-ichi Yamashita, Chief of Technical Department
Phone No.:	81 3 3216-4562
FAX No.:	81 3 3216-4581
Description:	
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Efforts to discuss their position with an appropriate representative have been unsuccessful.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples

*D=Developed or developing, E=Evaluating, U=Using

Type: Equipment Manufacturer

Name:	KLN Ultraschall GmbH
Address:	Siegfriedstr. 124 D-6148 Heppenheim Germany
Contact:	H. Gölz
Phone No.:	011-6252-14-0
FAX No.:	011-6262-14-277
Description:	KLN Ultraschall produces metal parts cleaning equipment, particularly involving the design of explosion-proof cleaning systems for used with alcohol-based solvent cleaners.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	KLN Ultraschall is not involved in any actual solvent development efforts but does develop cleaning equipment for use with volatile, flammable solvents.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples

*D=Developed or developing, E=Evaluating, U=Using

Type: Equipment Manufacturer

Name:	Martin Marietta
Address:	Martin Marietta Aerospace 6801 Rockledge Drive Bethesda, MA 20817
Contact:	
Phone No.:	301-897-6000
FAX No.:	
Description:	Major producer of aerospace equipment. Member of International Cooperative for Ozone Layer Protection (ICOLP) and UNEP Solvents, Coatings, and Adhesives, Technical Options Committee.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Developed MarClean semi-aqueous solvent cleaning process.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples
D/E	Semi-aqueous	Mixture		

*D=Developing, E=Evaluating, U=Using

Type: Equipment Manufacturer

Name:	Matsushita-Kotbuki Electronic Ind.
Address:	2-2-10, Lotobuki-machi Takamatsu City 760 Japan
Contact:	
Phone No.:	011 81 87 851-7228
FAX No.:	
Description:	Manufacturer of electronic equipment.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	It is believed that Matsushita-Kotbuki has information regarding the use of various alternative materials (i.e. 1,1,1-trichloroethane, HCFC's, and alcohol fluoride) in electronic cleaning applications. However, efforts to discuss their position with the appropriate representative have been unsuccessful.

CFC-113 Replacements or Alternatives:

D/ E/U*	**Name**	**CAS No.**	**Availability**	
			Comm.	**Samples**

*D=Developed or developing, E=Evaluating, U=Using

Type: Association/Research Institute

Name:	Molecular Knowledge Systems, Inc.
Address:	26-452 Kessler Farm Drive Nashua, NH 03063
Contact:	Dr. Kevin Joback
Phone No.:	603-881-9821
FAX No.:	603-881-3201
Description:	Provides computer software and consulting services to design and identify chemical structures/compounds suitable for a variety of end use applications, including CFC substitutes. Several of their molecular design and property estimation techniques are used widely throughout the chemical industry.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Molecular Knowledge Systems uses a three-step approach to identify substitutes: 1) thermodynamic and engineering analysis of existing CFC application to identify key property requirements, 2) design molecular structures using advanced computer and property estimation techniques; and 3) complete search for optimal substitute through detailed computer modeling and literature searching.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples

*D=Developed or developing, E=Evaluating, U=Using

Type: Chemical Producer

Name:	Montefluos S.P.A.
Address:	via Principe Eugenio 5 20155 Milan, Italy
Contact:	Dr. Sergio Lo Monaco, ADL consultant to Montefluos
Phone No.:	011-392-7601-5046
FAX No.:	011-392-783 022
Description:	Manufacturer of chemicals, solvents and polymers. Member of Alternative Fluorocarbons Environmental Acceptability Study.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Montefluos is currently evaluating their position in the CFC area, and will be developing a strategy. At this time, they do not produce any CFC (including CFC-113) replacement materials, nor are they developing any materials.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples

*D=Developed or developing, E=Evaluating, U=Using

Type: Equipment Manufacturer

Name:	Northern Telecom
Address:	3 Robert Speck Parkway Mississauga, Ontario Canada L4Z3C8
Contact:	Arthur Fitzgerald
Phone No.:	416-566-3048
FAX No.:	416-566-3348
Description:	Major producer of electronic and communications equipment. Member of International Cooperative for Ozone Layer Protection (ICOLP) and UNEP Solvents, Coatings, and Adhesives, Technical Options Committee.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Northern Telecom has been a leader in converting from CFC compounds and completed their worldwide phaseout of all CFC-113 uses in 1991. As alternatives, they are now using aqueous and semi-aqueous cleaning processes as well as production modifications to eliminate the necessity for solvent cleaning.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples

*D=Developing, E=Evaluating, U=Using

Type: Chemical Producer

Name:	PCR Inc.
Address:	P.O. Box 1466 Gainesville, FL 32602
Contact:	Dr. Rick Du Boisson
Phone No.:	1-800-331-6313
FAX No.:	904-371-6246
Description:	PCR manufactures a wide variety of halogenated compounds including CFCs and HCFCs in research, pilot, and limited commercial quantities.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	PCR will undertake research and development programs to develop or synthesize specific CFC substitutes. They are not competing with the larger chemical companies to produce a CFC-113 substitute but will supply R&D quantities of various CFC substitute at laboratory quantity prices.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples

*D=Developed or developing, E=Evaluating, U=Using

Type: Chemical Producer

Name:	Petroferm, Inc.
Address:	Specialty Chemicals 5400 First Coast Highway Fernandina, FL 32034
Contact:	Mike Hayes
Phone No.:	904-261-8286
FAX No.:	
Description:	Producer of terpene-based chemicals.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Developed BIOACT EC-7 and EC-7R line of terpene-based semi-aqueous cleaners as CFC-113 replacements. The BIOACT cleaners are claimed to be biodegradable, low toxicity, low evaporation rate, and effective for cleaning organic-based soils.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples
D	BIOACT EC-7	Mixture	Yes	Yes
D	BIOACT EC-7R	Mixture	Yes	Yes

*D=Developing, E=Evaluating, U=Using

Type: Association/Research Institute

Name:	Program for Alternative Fluorocarbon Testing (PAFT)
Address:	
Contact:	
Phone No.:	
FAX No.:	
Description:	Joint effort by eight HCFC producers to undertake extensive toxicity testing of several HCFC compounds proposed as CFC alternatives. Participating companies include Allied-Signal, Asahi Glass, Daikin, Dupont, Elf Atochem, ICI, Rhone Poulenc, and Showa Denko.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	While some initial test results have been released, detailed test results are not expected until 1993 for initial compounds and 1996 for PAFT IV compounds.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples

*D=Developed or developing, E=Evaluating, U=Using

Type: Equipment Manufacturer

Name:	Protonique SA
Address:	Route D'Echallens 3 Romanel-Sur-Lausanne, Switzerland 1032
Contact:	Brian Ellis
Phone No.:	011 41 21382 334
FAX No.:	
Description:	Cleaning specialists; actively involved in related professional organizations.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Protonique SA is a cleaning specialist and thus a user of CFC's. Ellis is a member of the UNEP committee and contributed to the writing of the UNEP report on CFC alternatives. Because he has very limited information in addition to the UNEP report, he suggests that our review of the report would be the most useful source of information. He did state that one new potential material has been introduced, but would not elaborate on it because its usefulness has not been demonstrated yet.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples

*D=Developed or developing, E=Evaluating, U=Using

Type: Association/Research Institute

Name:	Research Institute for Cleaning Technology
Address:	Germany
Contact:	Mr. Helmut Krussman
Phone No.:	011-49-21-51-770072
FAX No.:	011-49-21-51-770075
Description:	Research Organization
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	At the present time, perchloroethylene is essentially the only dry-cleaning material being used in Germany (small amounts of hydrocarbon solvents are also being used). However, as of December 31, 1992, the use of all halogenated materials will be banned (very few exceptions to this regulation are anticipated). As such, Germany is likely to be taking the world lead in researching non-halogenated cleaning materials. Currently, they are primarily investigating hydrocarbon materials, but are also evaluating some alcohols. At this time, Dr. Krussman believes the three top candidate materials are Shellsolve D-60S (Shell), Iospar H (Exxon), and Nippon N-11 (Nippon Oil). He believes that the terpenes are undesirable due to their odor and potential for allergic reaction. He also feels that best cleaning equipment is being manufactured by Tosei and Sensen, both Japanese companies.

CFC-113 Replacements or Alternatives:

D/E/U*	Name	CAS No.	Availability	
			Comm.	Samples
E	Shellsolve D-60S (Shell)		Y	NA
E	Isopar H (Exxon)		Y	NA
E	Nippon N-3 (Nippon Oil)		Y	NA

*D=Developing, E=Evaluating, U=Using

Type: Chemical Producer

Name:	Rhone-Poulenc Chemicals, Ltd.
Address:	ISC Division P.O. Box 46 Saint Andrews Road Avon Mouts Brisol Great Britain BS11 9YF
Contact:	Mr. Brian Paul
Phone No.:	011-44-272-823 631
FAX No.:	
Description:	Manufacturer of chemicals and solvents. Member of Alternative Fluorocarbon Environmental Acceptability Study.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Mr. Paul indicated that Rhone Poulenc supplies the perfluorocarbon materials (Flutec product line) used as the "blanket" material for the cleaning process developed by British Aerospace (see British Aerospace for more detail). These perfluorocarbons are used entirely as flame suppressants in the system, and are not appropriate as cleaning solvents. Mr. Paul stated that HCFC 141b may be an appropriate alternative for CFC-113. Rhone Poulenc has experimented with it in various cleaning applications (not fabric cleaning) with some success. HCFC 141b is sold by Rhone Poulenc, but not manufactured by them.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples
D	Perfluorocarbons			

*D=Developed or developing, E=Evaluating, U=Using

Type: Chemical Producer

Name:	SCM-Glidco
Address:	Foot of West 61st Street Jacksonville, Florida 33201
Contact:	Mr. Mike Wyatt, Product Manager/Mr. William Hoffman
Phone No.:	(904) 768-5800 exts. 327/322
FAX No.:	
Description:	World's largest and oldest manufacturer of terpenes.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Mr. Wyatt indicated that SCM-Glidco produces a series of terpene-based solvents (flash points = 120-140°F) which are environmentally safe and have proven to be successful in various cleaning, particularly metal cleaning. A limited amount of work has been performed in the fabric cleaning area. Mr. Hoffman stated that the materials have been successfully used to clean "shop" towels for a supplier of janitorial supplies. SCM-Glidco would be willing to perform trial cleaning experiments on military clothing to identify the most appropriate solvents. He believed that Glidsafe™ Glidsol 66-1 may be the most appropriate solvent for this application.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples
D	Glidsafe™ Glidsol 66-1	NA	Yes	Yes

*D=Developed or developing, E=Evaluating, U=Using

Type: Chemical Producer

Name:	Showa Denko
Address:	13-9, Shiba Daimon 1-Chome Minato-ku, Tokyo 105 Japan
Contact:	Hiroshi Ikeda
Phone No.:	03-5470-3166
FAX No.:	03-3433-2555
Description:	Chemical manufacturer of fluorocarbon-based materials. Actively involved in Japanese and International CFC replacement activities.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Mr. Ikeda indicated that as of this time Showa Denko has not developed an ideal replacement for CFC-113, but is performing considerable research in the area. Mr. Ikeda suggests that HCFC-225ca/cb may currently be the most promising alternative, although by the time the ultimate development and testing of the product is completed other substitutes may have fully taken over the market. He also indicates that HCFC-141b may be an important alternative for many CFC-113 applications.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples

*D=Developed or developing, E=Evaluating, U=Using

Type: Dry Cleaner

Name:	Sketchley Plc.
Address:	P.O. Box 7 Hinckley Liecestershire LE10 2NE United Kingdom
Contact:	Mike Clark
Phone No.:	011 44 455 238 133
FAX No.:	011 44 455 619 056
Description:	Sketchley Plc. operates approximately 500 drycleaning shops, the majority of which now use CFC-113 as the drycleaning solvent. They are actively involved in the UNEP Solvents, Coatings and Adhesives Technical Options Committee (Mike Clark is Chairman of Dry Cleaning Chapter Committee) as well as the British Textile Services Association and Fabric Care Research Association.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Although very knowledgeable of international activites regarding CFC-113 replacements, particularly for the drycleaning industry, Sketchley is not involved in developing CFC-113 replacements. At present, Sketchley has decided to replace their CFC-113 machines with perchloroethylene machines as old machines require replacing, estimated at approximately 50 machines per year. Sketchley states that perchloroethylene is actually better for cleaning and new state-of-the-art machines (Bowe, Elksberg, Germany) provide excellent performance with very low solvent emissions. Sketchly does not forsee the commercial availability of an alternative low-toxicity, low-flammability, environmentally acceptable CFC-113 replacement within the next few years.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples
E,U	Perchloroethylene	127-18-4	Y	Y

*D=Developed or developing, E=Evaluating, U=Using

Type: Association/Research Institute

Name:	Swedish Institute for Textile Research (TEFO)
Address:	Box 5402 S-40229 Gothenburg Sweden
Contact:	Mr. Harold Asnes
Phone No.:	011-46 31 20 01 75
FAX No.:	011-46 31 82 13 19
Description:	TEFO is a research institute run under the auspices of a semi-governmental regulatory board with a trade association membership of 89 companies. Research and development activities include the fields of fiber and textile technology, clothing, and laundering. TEFO is a member of the International Drycleaning Research Committee.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	TEFO has not undertaken much research regarding CFC-113 replacements for drycleaning applications but has completed some cleaning efficiency testing of isopropyl lactate, limonene, and dibasic esters of adipinic acid, glutaric acid, and succinic acid. TEFO reports that both CFC-113 (PEL=500 pm) and perchloroethylene (PEL=10 ppm) are now used in Sweden, with the CFC-113 phaseout for drycleaning applications set for end of 1994.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples

*D=Developed or developing, E=Evaluating, U=Using

Type: American/Research Institute

Name:	Textile Services Association Ltd.
Address:	7 Churchill Court 58 Station Road North Harrow, Middlesex Great Britain HA2 7SA
Contact:	
Phone No.:	011-081-863-7755
FAX No.:	
Description:	Association of British drycleaning and laundry industries that compiles and disseminates information of developments in washing and drycleaning technology and equipment. Publishers of "Safety in Drycleaning Guidelines" manual providing guidance regarding environmental and worker safety in the drycleaning operations, including information on solvent use and disposal issues.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	None, activities primarily involve information dissemination.

CFC-113 Replacements or Alternatives:

E/D*	Name	CAS No.	Availability	
			Comm.	Samples

*D=Developed or developing, E=Evaluating, U=Using

Type: Chemical Producer

Name:	3M	
Address:	3M Corporate Product Responsibility 3M Center Building 225-3N-09 St. Paul, MN 55144-1000	Industrial Chemical Products Division 3M Center Blding 223-6S-04 St. Paul, MN 55144-1000
Contact:	Dr. Donald R. Theissen, Director	Mr. Douglas Johnson
Phone No.:	612-733-6050	612-736-7629
FAX No.:	612-736-9278	
Description:	3M is a major producer of industrial chemicals, adhesives, and polymers.	
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	3M produces a range of perfluorocarbon chemicals which are being sold as CFC-113 replacements for some electronic parts cleaning/preparation applications, particularly focusing on removal of particulate matter or displacement of water. While several perfluorocarbons have the desired boiling point/heat of vaporization properties for the LADDS, these compounds tend to be very poor solvents and do not mix with many other solvents. Perfluorocarbons are not expected to be very effective as drycleaning solvents, but may provide some benefit as additives to other solvent systems, either as a stabilizer to reduce reactivity of aggressive solvents or to reduce flammability of mixtures. 3M is also working on halon replacements with U.S. Air Force and commercialization of perfluoro-morpholines as solvent alternatives.	

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples
D	Perfluorohexane (PF-5060/Fluorinert FC-72)	355-42-0	Y	Y
D	Perfluoroctane (PF-5080/Fluorinert FC-77)	307-34-6	Y	Y
D	Perfluoroheptane (PF-5070/Fluorinert FC-84)	335-57-9	Y	Y
D	Perfluoro-N-methylmorpholine	382-28-5	N	Y

*D=Developed or developing, E=Evaluating, U=Using

Type: Equipment Manufacturer

Name:	Toshiba Research and Development Center
Address:	1, Komukai Toshiba-cho Saiwai-ku, Kawasaki, 210 Japan
Contact:	Mr. Shigeo Matsui
Phone No.:	81 44 549-2293
FAX No.:	81 44 555-2074
Description:	Manufacturer of electronic equipment.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	It is believed that Toshiba has performed work in electronics cleaning, precision cleaning, and metal cleaning areas. Reportedly, they have work with cleaning products called Technocare FRW and FRV, which are silicone-based, non-water type materials. However, efforts to discuss their position with an appropriate representative were not successful.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples

*D=Developed or developing, E=Evaluating, U=Using

Type: Chemical Producer

Name:	Union Camp
Address:	P.O. Box 37617 Jacksonville, FL 32236
Contact:	Wayne Cristman
Phone No.:	904-783-2180
FAX No.:	
Description:	Union Camp is a major supplier of terpene-based chemicals. Union Camp supplies terpene-based raw materials to its affiliate, Bush Boake Allen, who modifies them to produce high performance terpene cleaning solvents.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	The terpene solvents produced by Bush Boake Allen are terpenes and terpene alcohols. These compounds have high boiling points and flashpoints of approximately 140°F. While relatively new to the market, these solvents are targeted as CFC-113 replacements for metal, electronics, and precision cleaning applications (see Bush Boake Allen for additional information).

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples

*D=Developed or developing, E=Evaluating, U=Using

Type: Association/Research Institute

Name:	University of Tennessee
Address:	Department of Chemistry Knoxville, TN 37996-1600
Contact:	Dr. James L. Adcock
Phone No.:	615-974-3391
FAX No.:	615-974-3454
Description:	University chemistry department.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Recently completed a program (February 1992) funded jointly by EPA and EPRI to synthesize and measure/estimate the physical properties of a series of fluorinated ethers as potential CFC replacements, primarily for refrigerant applications. While the research emphasis was on compounds with much lower boiling points than CFC-113, some of compounds synthesized may be suitable as CFC-113 replacements. Examples include pentafluoromethylethyl ether (HFE-245) and trifluoromethyl ether (HFE-143). Additional research to better characterize these compounds is necessary. Facilities and personnel at University of Tennessee would available for further compound synthesis and characterization work, under contract, if the Army identified such a need.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples
D	Pentafluoromethylethyl ether (HFE-245)		N	N
D	Trifluoromethyl ether (HFE-143)		N	N

*D=Developing, E=Evaluating, U=Using

Type: Government Agency

Name:	U.S. Air Force/Halon Alternatives Program
Address:	Air Base Protection Branch Air Force Civil Engineering Support Agency HQ AFCESA/RACF Tyndall Air Force Base, FL 32403-6001
Contact:	Capt. John R. Floden
Phone No.:	904-283-3734
FAX No.:	
Description:	The U.S. Air Force Halon Alternatives Program is an effort to develop, identify and evaluate alternative fire extinquishing media that have better environmental acceptability and desired extinquishment characteristics for Air Force applications. Their approach involves assessing applications, developing criteria, targeting and prioritizing candidates, and performing testing.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	While the Air Forces efforts have been targetted toward fire-extinquishing compounds, some of their requirements are similar to those for CFC-113 replacements. To date, their efforts have focussed on FCs, HFCs, HCFCs, and hydrobromofluorocarbons (HBFCs). As part of this work, they have compiled a computerized database of physical property, environmental characteristics, fire extinquishment concentrations, and toxicity information for over 670 halocarbon compounds. Physical property estimation algorithms have also been compiled. Recent efforts have focussed on evaluation perfluorohexane as a replacement for Halon 1211 streaming agent.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples
E	Perfluorohexane	355-42-0	Y	Y
E	HCFC-123	306-83-2	Y	Y

*D=Developing, E=Evaluating, U=Using

Type: Government Agency

Name:	U.S. Army Chemical Research, Development & Engineering Center (CRDEC)
Address:	SMCCR-PPD / Dec. Sys. Div. Aberdeen Proving Ground Maryland 21010-5423
Contact:	James Richmond
Phone No.:	301-671-5934
FAX No.:	
Description:	Through 1991, CRDEC's Decontamination Systems Division was developing the Non-Aqueous Equipment Decontamination System (NAEDS) which used CFC-113 as the cleaning solvent. CRDEC also maintains the Chemical-Biological Information Analysis Center (CBIAC) providing information search capabilities for U.S. defense related research.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Recently undertook information search and laboratory research effort to identify CFC-113 alternatives for use in the NAEDS. Because of difficulties in identifying suitable "drop-in" replacements for CFC-113 (as well as changes in deployment priorities), further efforts on the NAEDS were terminated in 1991. Although CRDEC investigated HCFCs as interim replacements, problems were identified with HCFC instability in the presence of decontaminating solutions (e.g., bleach). If they were to further pursue the (non-portable) NAEDS, efforts would be directed toward development of a semi-aqueous solvent wash/recycle process. Present plans are to restart design efforts for a mobile NAEDS in 1996.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples
E	HCFCs			
E	Semi-aqueous			

*D=Developing, E=Evaluating, U=Using

Type: Government Agency

Name:	U.S. Department of Energy/Oak Ridge National Laboratory
Address:	
Contact:	
Phone No.:	
FAX No.:	
Description:	
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	

CFC-113 Replacements or Alternatives:

D/ E/U*	**Name**	**CAS No.**	**Availability**	
			Comm.	**Samples**

*D=Developing, E=Evaluating, U=Using

Type: Government Agency

Name:	U.S. Environmental Protection Agency/ Air and Energy Research Laboratory
Address:	Industrial Process Branch (MD-62B) Research Triangle Park, North Carolina 27711
Contact:	N. Dean Smith
Phone No.:	919-541-2708
FAX No.:	
Description:	As one of their missions, the EPA Air and Energy Research Laboratory undertakes and supports research to develop CFC replacements for refrigeration, air conditioning, and insulation foam blowing applications. These activities include laboratory research as well as information dissemination.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Two programs have been recently completed (December 1991 and February 1992) to synthesize and measure/estimate the physical properties of two classes of compounds as potential CFC replacements, primarily for refrigerant applications. This work was carried out at Clemson University and the University of Tennessee and was funded jointly by the EPA and the Electric Power Research Institute. Efforts at Clemson University focussed on fluorinated propanes and butanes, while the efforts at University of Tennessee focussed on fluorinated ethers. While the research emphasis was on compounds with much lower boiling points than CFC-113, some of compounds synthesized may be suitable as CFC-113 replacements. Additional research to better characterize these compounds would be necessary.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples
D/E	Fluorinated butanes and propanes	NA	N	N
D/E	Fluorinated ethers	NA	N	N

*D=Developing, E=Evaluating, U=Using

Type: Government Agency

Name:	U.S. National Aeronautics and Space Administration/Kennedy Space Center
Address:	Materials Science Laboratory Kennedy Space Center, FL 32899
Contact:	Martha Williams
Phone No.:	407-867-3910
FAX No.:	
Description:	The Material Science Laboratory at NASA's Kennedy Space Center was tasked in 1990 to develop alternative cleaning processes to replace CFC-113 for removal of particles and non-volatile residues from piping, tanks, valved, regulators, etc., associated with the Space Shuttle launch process.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Evaluating aqueous and semi-aqueous cleaning processes, including low pressure impingement and ultrasonication. Methods have also been developed to assess cleaning effectiveness. These include liquid attenuated total reflectance, surface tension, total organic carbon, turbidity, and ultraviolet fluorescence scattering.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples
D/E	Aqueous cleaners	Mixtures	Yes	Yes
D/E	Semi-aqueous cleaners	Mixtures	Yes	Yes

*D=Developing, E=Evaluating, U=Using

Type: Chemical Producer

Name:	W.R. Grace & Co.
Address:	55 Hayden Avenue Lexington, MA 02173
Contact:	Mr. Steven Freithas
Phone No.:	617-861-6600
FAX No.:	
Description:	Producer of chemicals, solvents, and additives.
Summary of CFC-113 Replacement or Alternative Solvent Efforts:	Developed aqueous and semi-aqueous cleaners (Daraclean 282) as CFC-113 substitutes for metal and electronic parts cleaning operations through a joint program with Boeing.

CFC-113 Replacements or Alternatives:

D/ E/U*	Name	CAS No.	Availability	
			Comm.	Samples
D	Aqueous Cleaners	Mixture	Y	Y
D	Semi-aqueous Cleaners	Mixture	Y	Y

*D=Developed or developing, E=Evaluating, U=Using

INDEX OF INFORMATION SOURCES

APPENDIX B

SOLVENT PROPERTIES

Solvent Type		CFC	Alcohol	Alcohol
Chemical/Product Name		1,1,2-Trichloro-1,2,2-trifluoroethane	Ethanol	Methanol
ASHRAE Designation		CFC-113		
CAS Number		76-13-1	64-17-5	67-56-1
Composition/Formula		CCl2FCClF2	CH3CH2OH	CH3OH
Manufacturer/Vendor		Several	Several	Several
Environ.	ODP	0.80	0	0
Acceptability	GWP	1.30		
Physical	Molecular weight (daltons)	187	46	32
Properties	Boiling Point (F)	118	173	148.46
	Heat of Vap. (kcal/kg)	36.1		263
	Vap. Press. (mmHg at 70F)	334	45.7	100
	Density (g/cm^3)	1.56	0.79	0.79
	Viscosity (cP)	0.79		
	Surf. Ten. (dyne/cm)	17.3		
Flammability	Flashpoint (F)	None	55	54
	Firepoint (F)	None		
	Flam. Lmt/Lower (% vol)	None	3.5	6
	Flam. Lmt/Upper (% vol)	None	19	36.5
Toxicity	OSHA/ACGIH PEL (8hr TWA)	1000 ppm	1000 ppm	200 ppm
	LC50 Inhalation			
	LD50 Skin			
	LD50 Oral			
	Carcinogen (Y/N/Suspect)	N	N	N
Cleaning/	Solubility Parameter	7.3		
Materials	Kauri-Butanol value	31		
Compatibility	Comp. with Metals	Good	Good	
	Comp. with Elast./Plastics	Good	Good	
	Comp. with Fabrics/Finishes	Good	Good/Aggressive	
	Int. with CW/Decon Agents			
Availability	Commercial (Y/N/Date)	Y (until 1995)	Y	Y
	Samples (Y/N/Date)	Y (until 1995)	Y	Y
	Price ($/lb)			
Potential for Success		Not applicable	Low/Flammable solvent	Low/Flammable solvent

APPENDIX B. SOLVENT PROPERTIES

Solvent Type		Chlorinated Solvent	Chlorinated Solvent	Chlorinated Solvent
Chemical/Product Name		Isopropyl Chloride	Methyl Chloroform	Methylene Chloride
		(2-Chloropropane)	(1,1,1-Trichloroethane)	(1,1-Dichloromethane)
ASHRAE Designation				
CAS Number		26446-76-4	71-55-6	75-09-2
Composition/Formula		CH3CHClCH3	CH3CCl3	CH2Cl2
Manufacturer/Vendor			Dow, ICI, PPG, Vulcan	Dow, LCP, Occid.
Environ.	ODP	0.003	0.15	0
Acceptability	GWP	0.01	0.02	
Physical	Molecular weight (daltons)	78	133	85
Properties	Boiling Point (F)	95	165	103
	Heat of Vap. (kcal/kg)		56.7	78.9
	Vap. Press. (mmHg at 70F)		109	340-382
	Density (g/cm^3)		1.34	1.33
	Viscosity (cP)		0.79	0.41
	Surf. Ten. (dyne/cm)		25.6	27.1
Flammability	Flashpoint (F)	< 0	None	None
	Firepoint (F)			
	Flam. Lmt/Lower (% vol)		7.5	12
	Flam. Lmt/Upper (% vol)		16	19
Toxicity	OSHA/ACGIH PEL (8hr TWA)	High toxicity	350 ppm	500 ppm
	LC50 Inhalation			
	LD50 Skin			
	LD50 Oral			
	Carcinogen (Y/N/Suspect)		Suspect	Suspect
Cleaning/	Solubility Parameter		8.5	9.9
Materials	Kauri-Butanol value		124	132
Compatibility	Comp. with Metals	Good	Good	Good
	Comp. with Elast./Plastics	Good	Aggressive, swells some elastomers	Aggressive, swells some elastomers
	Comp. with Fabrics/Finishes	Good	Good	Good
	Int. with CW/Decon Agents			
Availability	Commercial (Y/N/Date)	Y	Y (Phaseout in 1996)	Y
	Samples (Y/N/Date)	Y	Y	Y
	Price ($/lb)			
Potential for Success		Low/flammable solvent	Low/Scheduled for 1996 phaseout	Low/explosive vapor

Solvent Type		Chlorinated Solvent	Chlorinated Solvent	Ether
Chemical/Product Name		Perchloroethylene	Trichloroethylene	Methyl tert-Butyl Ether
		(Tetrachloroethylene)		
ASHRAE Designation				
CAS Number		127-18-4	79-01-6	1634-04-4
Composition/Formula		CCl2CCl2	CHClCCl2	CH3OC(CH3)3
Manufacturer/Vendor		Several	Several	Several
Environ.	ODP	0	0	0
Acceptability	GWP			
Physical	Molecular weight (daltons)	166	131	88
Properties	Boiling Point (F)	250	189	131
	Heat of Vap. (kcal/kg)	50.1	56.4	76
	Vap. Press. (mmHg at 70F)	0	60	0.045
	Density (g/cm^3)	1.62	1.46	0.74
	Viscosity (cP)	0.84	0.54	
	Surf. Ten. (dyne/cm)	32.3	28.5	
Flammability	Flashpoint (F)	None	None (90)	-18/14
	Firepoint (F)	None		
	Flam. Lmt/Lower (% vol)	None	8	2
	Flam. Lmt/Upper (% vol)	None	10.5	15.1
Toxicity	OSHA/ACGIH PEL (8hr TWA)	25 ppm	50 ppm	
	LC50 Inhalation			
	LD50 Skin			
	LD50 Oral			
	Carcinogen (Y/N/Suspect)	Suspect	Suspect	
Cleaning/	Solubility Parameter	9.3	9.3	
Materials	Kauri-Butanol value	91	130	
Compatibility	Comp. with Metals	Good		
	Comp. with Elast./Plastics	Good		
	Comp. with Fabrics/Finishes	Good		
	Int. with CW/Decon Agents			
Availability	Commercial (Y/N/Date)	Y		
	Samples (Y/N/Date)	Y		
	Price ($/lb)			
Potential for Success		Med/High boiling point	Med/High boiling point	Low/flammable solvent

APPENDIX B. SOLVENT PROPERTIES

Solvent Type		FC	FC	FC
Chemical/Product Name		Perfluorocarbon PF6	Perfluoro-1,3-dimethylcyclo-butane	Perfluoro-1,3-dimethylcyclo-hexane
ASHRAE Designation				
CAS Number				
Composition/Formula			C6F12	C8F16
Manufacturer/Vendor		Rhone Poulenc/ISC	Unknown (Dupont no longer pursuing)	Unknown
Environ. Acceptability	ODP		0	
	GWP			
Physical Properties	Molecular weight (daltons)		294	
	Boiling Point (F)		113	
	Heat of Vap. (kcal/kg)			
	Vap. Press. (mmHg at 70F)		377	
	Density (g/cm^3)			
	Viscosity (cP)			
	Surf. Ten. (dyne/cm)			
Flammability	Flashpoint (F)	None	None	None
	Firepoint (F)	None	None	None
	Flam. Lmt/Lower (% vol)	None	None	None
	Flam. Lmt/Upper (% vol)	None	None	None
Toxicity	OSHA/ACGIH PEL (8hr TWA)			
	LC50 Inhalation			
	LD50 Skin			
	LD50 Oral			
	Carcinogen (Y/N/Suspect)	N	N	N
Cleaning/ Materials Compatibility	Solubility Parameter			
	Kauri-Butanol value			
	Comp. with Metals			
	Comp. with Elast./Plastics			
	Comp. with Fabrics/Finishes		Poor solvent	Poor solvent
	Int. with CW/Decon Agents			
Availability	Commercial (Y/N/Date)	Y	N	N
	Samples (Y/N/Date)	Y	N	N
	Price ($/lb)			
Potential for Success		Low/poor cleaning performance	Low/poor cleaning performance	Low/poor cleaning performance

Solvent Type		FC	FC	FC
Chemical/Product Name		Perfluoroctane	Perfluoroheptane	Perfluorohexane
		(PF-5080 or Fluorinert FC-77)	(PF-5070 or Fluorinert FC-84)	(PF-5060 or Fluorinert FC-72)
ASHRAE Designation				FC-5-1-14
CAS Number		307-34-6	335-57-9	355-42-0
Composition/Formula		C8F18	C7F16	C6F14
Manufacturer/Vendor		3M	3M	3M
Environ. Acceptability	ODP	0	0	0
	GWP			
Physical Properties	Molecular weight (daltons)	438	388	338
	Boiling Point (F)	214	176	132.8
	Heat of Vap. (kcal/kg)	22.0	19.0	21
	Vap. Press. (mmHg at 70F)			
	Density (g/cm^3)	1.78	1.70	1.68
	Viscosity (cP)	1.42		0.67
	Surf. Ten. (dyne/cm)	15.0	13.0	12.0
Flammability	Flashpoint (F)	None	None	None
	Firepoint (F)	None	None	None
	Flam. Lmt/Lower (% vol)	None	None	None
	Flam. Lmt/Upper (% vol)	None	None	None
Toxicity	OSHA/ACGIH PEL (8hr TWA)			
	LC50 Inhalation			
	LD50 Skin			
	LD50 Oral			
	Carcinogen (Y/N/Suspect)	N	N	N
Cleaning/ Materials Compatibility	Solubility Parameter			
	Kauri-Butanol value			
	Comp. with Metals	Good	Good	Good
	Comp. with Elast./Plastics	Good except PVC, PTFE	Good except PVC, PTFE	Good except PVC, PTFE
	Comp. with Fabrics/Finishes	Poor solvents/oil removal	Poor solvents/oil removal	Poor solvents/oil removal
	Int. with CW/Decon Agents	Unknown	Unknown	Unknown
Availability	Commercial (Y/N/Date)	Y	Y	Y
	Samples (Y/N/Date)	Y	Y	Y
	Price ($/lb)			$12/lb
Potential for Success		Low/poor cleaning performance	Low/poor cleaning performance	Low/poor cleaning performance

Solvent Type		FC	Fluorinated Alcohol	Fluorinated Alcohol
Chemical/Product Name		Perfluoropentane	Pentafluoropropanol	Trifluoroethanol
		(PF-5050)		
ASHRAE Designation				
CAS Number		678-26-2		
Composition/Formula		C5F12	CF3CF2CH2OH	CF3CH2OH
Manufacturer/Vendor		3M	Nikkon	Halocarbon Products
Environ. Acceptability	ODP	0	0	0
	GWP			
Physical Properties	Molecular weight (daltons)	288	145	100
	Boiling Point (F)	86		165
	Heat of Vap. (kcal/kg)	21		82.8
	Vap. Press. (mmHg at 70F)			79
	Density (g/cm^3)			1.38
	Viscosity (cP)	0.65		
	Surf. Ten. (dyne/cm)	9.5		
Flammability	Flashpoint (F)	None		92
	Firepoint (F)	None		None
	Flam. Lmt/Lower (% vol)	None		5.5
	Flam. Lmt/Upper (% vol)	None		42
Toxicity	OSHA/ACGIH PEL (8hr TWA)			
	LC50 Inhalation			
	LD50 Skin			
	LD50 Oral			
	Carcinogen (Y/N/Suspect)	N	N	N
Cleaning/ Materials Compatibility	Solubility Parameter			
	Kauri-Butanol value			
	Comp. with Metals	Good		Good
	Comp. with Elast./Plastics	Good except PVC, PTFE		Good
	Comp. with Fabrics/Finishes	Poor solvents/oil removal		Good
	Int. with CW/Decon Agents	Unknown		Unknown
Availability	Commercial (Y/N/Date)	Y		Y
	Samples (Y/N/Date)	Y		Y
	Price ($/lb)	$12/lb		$16
Potential for Success		Low/poor cleaning performance	Unknown	Low/flammable solvent

Solvent Type		Fluorinated Ether	Fluorinated Ether	Fluorinated Ether
Chemical/Product Name		Pentafluoromethylethyl ether	Tetrafluoromethyl ethyl ether	Trifluorodimethyl ether
ASHRAE Designation		HFE-245	HFE-254	HFE-143
CAS Number				
Composition/Formula		CF2HOCHFCF2H	CH2FOCHFCF2H	CF2HOCH2F
Manufacturer/Vendor		EPA/EPRI/Univ. of Tenn.	EPA/EPRI/Univ. of Tenn.	EPA/EPRI/Univ. of Tenn.
Environ. Acceptability	ODP	0	0	0
	GWP			
Physical Properties	Molecular weight (daltons)			
	Boiling Point (F)	127	158	86
	Heat of Vap. (kcal/kg)			311
	Vap. Press. (mmHg at 70F)			
	Density (g/cm^3)			
	Viscosity (cP)			
	Surf. Ten. (dyne/cm)			
Flammability	Flashpoint (F)			
	Firepoint (F)			
	Flam. Lmt/Lower (% vol)			
	Flam. Lmt/Upper (% vol)			
Toxicity	OSHA/ACGIH PEL (8hr TWA)			
	LC50 Inhalation	7%		
	LD50 Skin			
	LD50 Oral			
	Carcinogen (Y/N/Suspect)			
Cleaning/ Materials Compatibility	Solubility Parameter			
	Kauri-Butanol value			
	Comp. with Metals			
	Comp. with Elast./Plastics			
	Comp. with Fabrics/Finishes			
	Int. with CW/Decon Agents			
Availability	Commercial (Y/N/Date)	N	N	
	Samples (Y/N/Date)	N	N	N
	Price ($/lb)			N
Potential for Success		Unknown	Unknown	Unknown

APPENDIX B. SOLVENT PROPERTIES

Solvent Type		Fluorinated Ether	Fluorinated Other	Fluorinated Other
Chemical/Product Name		Difluorodimethyl ether	Perfluoro-N-isopropylmorpholine	Perfluoro-N-methylmorpholine
			(PF-5072)	(PF-5052)
ASHRAE Designation		HFE-152		
CAS Number			1600-71-1	382-28-5
Composition/Formula		CH2FOCH2F	C7F15NO	C5F11NO
Manufacturer/Vendor		EPA/EPRI/Univ. of Tenn.	3M	3M
Environ.	ODP	0	0	0
Acceptability	GWP			
Physical	Molecular weight (daltons)		399	299
Properties	Boiling Point (F)	91	203	122
	Heat of Vap. (kcal/kg)			25
	Vap. Press. (mmHg at 70F)			274
	Density (g/cm^3)		1.79	1.7
	Viscosity (cP)			
	Surf. Ten. (dyne/cm)			
Flammability	Flashpoint (F)		None	None
	Firepoint (F)		None	None
	Flam. Lmt/Lower (% vol)		None	None
	Flam. Lmt/Upper (% vol)		None	None
Toxicity	OSHA/ACGIH PEL (8hr TWA)			
	LC50 Inhalation			
	LD50 Skin			
	LD50 Oral			
	Carcinogen (Y/N/Suspect)			
Cleaning/	Solubility Parameter			6.3
Materials	Kauri-Butanol value			
Compatibility	Comp. with Metals			
	Comp. with Elast./Plastics			
	Comp. with Fabrics/Finishes			
	Int. with CW/Decon Agents			
Availability	Commercial (Y/N/Date)	N	N	N
	Samples (Y/N/Date)	N	N	Y
	Price ($/lb)			
Potential for Success		Unknown	Low/High boiling point	Unknown

Solvent Type		Fluorinated Other	HCFC	HCFC
Chemical/Product Name		Perfluoro-N-ethylmorpholine (PF-5062)	Trichlorodifluoroethane	2,2-Dichloro-1,1,1-trifluoroethane
ASHRAE Designation			HCFC-122	HCFC-123
CAS Number		55716-11-5		306-83-2
Composition/Formula		C6F13NO	CClF2CHCl2	CF3CHCl2
Manufacturer/Vendor		3M	PCR	Allied, Dupont, Halocarbon, ICI
Environ. Acceptability	ODP	0		0.02
	GWP			0.02
Physical Properties	Molecular weight (daltons)	349	170	153
	Boiling Point (F)	162	162	82-84
	Heat of Vap. (kcal/kg)	23		41.1
	Vap. Press. (mmHg at 70F)			589
	Density (g/cm^3)	1.74	1.56	1.47
	Viscosity (cP)			
	Surf. Ten. (dyne/cm)			
Flammability	Flashpoint (F)	None		None
	Firepoint (F)	None		
	Flam. Lmt/Lower (% vol)	None		
	Flam. Lmt/Upper (% vol)	None		
Toxicity	OSHA/ACGIH PEL (8hr TWA)		High toxicity	10 ppm by manu. (PAFT/1993)
	LC50 Inhalation			
	LD50 Skin			
	LD50 Oral			
	Carcinogen (Y/N/Suspect)		N	N
Cleaning/ Materials Compatibility	Solubility Parameter			7.0
	Kauri-Butanol value			
	Comp. with Metals			
	Comp. with Elast./Plastics			
	Comp. with Fabrics/Finishes			
	Int. with CW/Decon Agents			
Availability	Commercial (Y/N/Date)	N		
	Samples (Y/N/Date)	N		
	Price ($/lb)		>$30/lb	$5/lb
Potential for Success		Unknown	Med	Med

APPENDIX B. SOLVENT PROPERTIES

Solvent Type		HCFC	HCFC	HCFC
Chemical/Product Name		1,2-Dichloro-1,2,2-trifluoroethane	1,2-Dichloro-1,2-difluoroethane	1,1-Dichloro-2,2-difluoroethane
ASHRAE Designation		HCFC-123a	HCFC-132	HCFC-132a
CAS Number				
Composition/Formula		CClF2CHClF	CHClFCHClF	CHF2CHCl2
Manufacturer/Vendor		PCR	PCR	PCR
Environ. Acceptability	ODP	0.02		
	GWP			
Physical Properties	Molecular weight (daltons)			
	Boiling Point (F)	84	137	140
	Heat of Vap. (kcal/kg)	41.1		
	Vap. Press. (mmHg at 70F)			
	Density (g/cm^3)	1.50	1.47	1.49
	Viscosity (cP)			
	Surf. Ten. (dyne/cm)			
Flammability	Flashpoint (F)	None	None	None
	Firepoint (F)		None	None
	Flam. Lmt/Lower (% vol)		None	None
	Flam. Lmt/Upper (% vol)		None	None
Toxicity	OSHA/ACGIH PEL (8hr TWA)		High toxicity	High toxicity
	LC50 Inhalation			
	LD50 Skin			
	LD50 Oral			
	Carcinogen (Y/N/Suspect)	N		
Cleaning/ Materials Compatibility	Solubility Parameter	7.4		
	Kauri-Butanol value			
	Comp. with Metals			
	Comp. with Elast./Plastics			
	Comp. with Fabrics/Finishes			
	Int. with CW/Decon Agents			
Availability	Commercial (Y/N/Date)		N	N
	Samples (Y/N/Date)		Y	Y
	Price ($/lb)			
Potential for Success		Med	Med	Med

Solvent Type		HCFC	HCFC	HCFC
Chemical/Product Name		1,2-Dichloro-1,1-difluoroethane	1,1-Dichloro-1-fluoroethane	1,2-Dichloro-1,2,3,3,3-pentafluoro-propane
ASHRAE Designation		HCFC-132b	HCFC-141b	HCFC-225ba
CAS Number		1649-08-7	1717-00-6	
Composition/Formula		CF2ClCH2Cl	CH3CCl2F	CF3CFClCFHCl
Manufacturer/Vendor		PCR	Atochem, Allied	EPA/EPRI/Clemson
Environ. Acceptability	ODP		0.15	
	GWP		0.09	
Physical Properties	Molecular weight (daltons)	135	117	203
	Boiling Point (F)	. 116	89-90	125
	Heat of Vap. (kcal/kg)		52.8	
	Vap. Press. (mmHg at 70F)		518	
	Density (g/cm^3)	1.42	1.24	
	Viscosity (cP)		0.42	
	Surf. Ten. (dyne/cm)		19.3	
Flammability	Flashpoint (F)	None		None
	Firepoint (F)	None		None
	Flam. Lmt/Lower (% vol)	None	7.6	None
	Flam. Lmt/Upper (% vol)	None	17.7	None
Toxicity	OSHA/ACGIH PEL (8hr TWA)	High toxicity	(PAFT/1993)	
	LC50 Inhalation			
	LD50 Skin			
	LD50 Oral			
	Carcinogen (Y/N/Suspect)			
Cleaning/ Materials Compatibility	Solubility Parameter		7.6-7.9	
	Kauri-Butanol value		56	
	Comp. with Metals		Good	Good
	Comp. with Elast./Plastics		Aggressive	Good
	Comp. with Fabrics/Finishes		Aggressive	Good
	Int. with CW/Decon Agents		Unknown	Poor stability with bleach
Availability	Commercial (Y/N/Date)	N	Y	N
	Samples (Y/N/Date)	Y	Y	N
	Price ($/lb)	>$100/lb		
Potential for Success		Med	Med	Med

APPENDIX B. SOLVENT PROPERTIES

Solvent Type		HCFC	HCFC	HCFC
Chemical/Product Name		1,1-Dichloro-2,2,3,3,3-pentafluoro-propane	1,3-Dichloro-1,1,2,2,3-pentafluoro-propane	1,2-Dichloro-1,1,3,3,3-pentafluoro-propane
ASHRAE Designation		HCFC-225ca	HCFC-225cb	HCFC-225da
CAS Number				
Composition/Formula		CF3CF2CHCl2	CClF2CF2CHClF	CClF2CHClCF3
Manufacturer/Vendor		Akzo, Asahi, Central, Daiken, ICI	Akzo, Asahi, Central, Daiken, ICI	PCR, EPA/EPRI/Clemson
Environ. Acceptability	ODP	0.05	0.05	
	GWP	0.03	0.10	
Physical Properties	Molecular weight (daltons)	203	203	203
	Boiling Point (F)	124	133	123
	Heat of Vap. (kcal/kg)			
	Vap. Press. (mmHg at 70F)			
	Density (g/cm^3)	1.55	1.56	
	Viscosity (cP)	0.58-0.59	0.60-0.61	
	Surf. Ten. (dyne/cm)	15.8-16.3	16.7-17.7	
Flammability	Flashpoint (F)	None	None	None
	Firepoint (F)	None	None	None
	Flam. Lmt/Lower (% vol)	None	None	None
	Flam. Lmt/Upper (% vol)	None	None	None
Toxicity	OSHA/ACGIH PEL (8hr TWA)	(PAFT/1993)	(PAFT/1993)	
	LC50 Inhalation			
	LD50 Skin			
	LD50 Oral	> 5 g/Kg	> 5 g/Kg	
	Carcinogen (Y/N/Suspect)			
Cleaning/ Materials Compatibility	Solubility Parameter			
	Kauri-Butanol value	34	30	
	Comp. with Metals	Good	Good	Good
	Comp. with Elast./Plastics	Good	Good	Good
	Comp. with Fabrics/Finishes	Good	Good	Good
	Int. with CW/Decon Agents	Poor stability with bleach	Poor stability with bleach	Poor stability with bleach
Availability	Commercial (Y/N/Date)	Y	Y	N
	Samples (Y/N/Date)	Y	Y	Y
	Price ($/lb)			
Potential for Success		Med	Med	Med

Solvent Type		HCFC	HFC	HFC
Chemical/Product Name		Chlorotetrafluoropropane	Difluoroethane	Octafluorobutane
ASHRAE Designation		HCFC-244ca	HFC-152	HFC-338
CAS Number				
Composition/Formula		CHF2CF2CH2Cl	CH2FCH2F	HCF2CF2CF2CF2H
Manufacturer/Vendor		EPA/EPRI/Clemson	PCR	EPA/EPRI/Clemson
Environ. Acceptability	ODP		0	0
	GWP			
Physical Properties	Molecular weight (daltons)	150	66	
	Boiling Point (F)	131	87	109
	Heat of Vap. (kcal/kg)			
	Vap. Press. (mmHg at 70F)			
	Density (g/cm^3)		0.91	
	Viscosity (cP)			
	Surf. Ten. (dyne/cm)			
Flammability	Flashpoint (F)	None		
	Firepoint (F)	None		
	Flam. Lmt/Lower (% vol)	None		
	Flam. Lmt/Upper (% vol)	None		
Toxicity	OSHA/ACGIH PEL (8hr TWA)			
	LC50 Inhalation			
	LD50 Skin			
	LD50 Oral			
	Carcinogen (Y/N/Suspect)	N		
Cleaning/ Materials Compatibility	Solubility Parameter			
	Kauri-Butanol value			
	Comp. with Metals			
	Comp. with Elast./Plastics			
	Comp. with Fabrics/Finishes			
	Int. with CW/Decon Agents			
Availability	Commercial (Y/N/Date)		N	N
	Samples (Y/N/Date)		N	Y
	Price ($/lb)			
Potential for Success		Unknown	Unknown	Unknown

APPENDIX B. SOLVENT PROPERTIES

Solvent Type		HFC	HFC	Hydrocarbon ester
Chemical/Product Name		Fluorocyclobutane	Fluorocyclobutane	Exxate 800/1000
ASHRAE Designation				
CAS Number		C-326d	C-326d	
Composition/Formula		trans-CF2CF2CHFCHF (cyclic)	cis-CF2CF2CHFCHF (cyclic)	
Manufacturer/Vendor		EPA/EPRI/Clemson	EPA/EPRI/Clemson	Exxon
Environ.	ODP	0	0	0
Acceptability	GWP			
Physical	Molecular weight (daltons)			
Properties	Boiling Point (F)	79	150	>300
	Heat of Vap. (kcal/kg)			
	Vap. Press. (mmHg at 70F)			
	Density (g/cm^3)			
	Viscosity (cP)			
	Surf. Ten. (dyne/cm)			
Flammability	Flashpoint (F)			171 - 212
	Firepoint (F)			
	Flam. Lmt/Lower (% vol)			
	Flam. Lmt/Upper (% vol)			
Toxicity	OSHA/ACGIH PEL (8hr TWA)			
	LC50 Inhalation			
	LD50 Skin			
	LD50 Oral			
	Carcinogen (Y/N/Suspect)			N
Cleaning/	Solubility Parameter			
Materials	Kauri-Butanol value			
Compatibility	Comp. with Metals			
	Comp. with Elast./Plastics			
	Comp. with Fabrics/Finishes			
	Int. with CW/Decon Agents			
Availability	Commercial (Y/N/Date)	N	N	Y
	Samples (Y/N/Date)	N	N	Y
	Price ($/lb)			
Potential for Success		Low	Low	Low/High boiling point

Solvent Type		Hydrocarbon	Hydrocarbon	Hydrocarbon
Chemical/Product Name		Axarel 9100	Axarel 6100	N-Paraffin (C13)
ASHRAE Designation				
CAS Number				
Composition/Formula				
Manufacturer/Vendor		DuPont	DuPont	Several
Environ. Acceptability	ODP	0	0	0
	GWP			
Physical Properties	Molecular weight (daltons)			
	Boiling Point (F)	>300	> 300	350-395
	Heat of Vap. (kcal/kg)			
	Vap. Press. (mmHg at 70F)			
	Density (g/cm^3)			0.76
	Viscosity (cP)			
	Surf. Ten. (dyne/cm)			
Flammability	Flashpoint (F)	205	154	
	Firepoint (F)			
	Flam. Lmt/Lower (% vol)			
	Flam. Lmt/Upper (% vol)			
Toxicity	OSHA/ACGIH PEL (8hr TWA)			
	LC50 Inhalation			
	LD50 Skin			
	LD50 Oral			
	Carcinogen (Y/N/Suspect)	N		N
Cleaning/ Materials Compatibility	Solubility Parameter			
	Kauri-Butanol value			22
	Comp. with Metals			
	Comp. with Elast./Plastics			
	Comp. with Fabrics/Finishes			
	Int. with CW/Decon Agents			
Availability	Commercial (Y/N/Date)	Y	Y	Y
	Samples (Y/N/Date)	Y	Y	Y
	Price ($/lb)			
Potential for Success		Low/High boiling point	Low/High boiling point	Low/High boiling point

Solvent Type		Hydrocarbon	Hydrocarbon	Hydrocarbon
Chemical/Product Name		Actrel	Kerosene	Axarel 38
ASHRAE Designation				
CAS Number				
Composition/Formula				
Manufacturer/Vendor		Exxon		DuPont
Environ. Acceptability	ODP	0	0	0
	GWP			
Physical Properties	Molecular weight (daltons)			
	Boiling Point (F)	300-360	330-495	
	Heat of Vap. (kcal/kg)			
	Vap. Press. (mmHg at 70F)			
	Density (g/cm^3)		0.79	
	Viscosity (cP)			
	Surf. Ten. (dyne/cm)			
Flammability	Flashpoint (F)		130	
	Firepoint (F)			
	Flam. Lmt/Lower (% vol)			
	Flam. Lmt/Upper (% vol)			
Toxicity	OSHA/ACGIH PEL (8hr TWA)			
	LC50 Inhalation			
	LD50 Skin			
	LD50 Oral			
	Carcinogen (Y/N/Suspect)		N	
Cleaning/ Materials Compatibility	Solubility Parameter			
	Kauri-Butanol value		30	
	Comp. with Metals			
	Comp. with Elast./Plastics			
	Comp. with Fabrics/Finishes			
	Int. with CW/Decon Agents			
Availability	Commercial (Y/N/Date)	Y	Y	Y
	Samples (Y/N/Date)	Y	Y	Y
	Price ($/lb)			$4.5/lb
Potential for Success		Low/High boiling point	Low/High boiling point	Low/High boiling point

Solvent Type		Hydrocarbon	Ketone	Ketone
Chemical/Product Name		Mineral Spirits	Acetone	Methyl ethyl ketone
			(2-Propanone)	
ASHRAE Designation				
CAS Number		64475-85-0	67-64-1	78-93-3
Composition/Formula			CH3COCH3	CH3COCH2CH3
Manufacturer/Vendor		Several	Several	Several
Environ.	ODP	0	0	0.00
Acceptability	GWP			
Physical	Molecular weight (daltons)		58	72
Properties	Boiling Point (F)	320-340	132-134	174-177
	Heat of Vap. (kcal/kg)		124	106.0
	Vap. Press. (mmHg at 70F)	2	195	85
	Density (g/cm^3)	0.76	0.79	0.81
	Viscosity (cP)			
	Surf. Ten. (dyne/cm)			
Flammability	Flashpoint (F)	105-200	0.0	16-28
	Firepoint (F)			
	Flam. Lmt/Lower (% vol)	0.8	2.6	1.8
	Flam. Lmt/Upper (% vol)	5	12.8	11.5
Toxicity	OSHA/ACGIH PEL (8hr TWA)		750 ppm	200 ppm
	LC50 Inhalation			
	LD50 Skin			
	LD50 Oral			
	Carcinogen (Y/N/Suspect)	N	N	N
Cleaning/	Solubility Parameter			
Materials	Kauri-Butanol value	32		
Compatibility	Comp. with Metals		Good	
	Comp. with Elast./Plastics		Aggresive	
	Comp. with Fabrics/Finishes		Good/Aggresive	
	Int. with CW/Decon Agents			
Availability	Commercial (Y/N/Date)	Y	Y	Y
	Samples (Y/N/Date)	Y	Y	Y
	Price ($/lb)			
Potential for Success		Low/High boiling point	Low/Flammable solvent	Low/Flammable solvent

APPENDIX B. SOLVENT PROPERTIES

Solvent Type		Ketone	Mixture/Azeotrope	Mixture/Azeotrope
Chemical/Product Name		Cyclohexanone	Genesolve 2020	KCD
ASHRAE Designation				
CAS Number		108-94-1		
Composition/Formula		(CH2)5CO	HCFC-141b	HCFC-141b
			HCFC-123	HCFC-123
Manufacturer/Vendor		Several	Allied	DuPont
Environ. Acceptability	ODP	0.00		
	GWP			
Physical Properties	Molecular weight (daltons)	98		
	Boiling Point (F)	312		
	Heat of Vap. (kcal/kg)			
	Vap. Press. (mmHg at 70F)	21		
	Density (g/cm^3)	1		
	Viscosity (cP)			
	Surf. Ten. (dyne/cm)			
Flammability	Flashpoint (F)	111-145		
	Firepoint (F)			
	Flam. Lmt/Lower (% vol)	1.1		
	Flam. Lmt/Upper (% vol)	9.4		
Toxicity	OSHA/ACGIH PEL (8hr TWA)	100.0		
	LC50 Inhalation			
	LD50 Skin			
	LD50 Oral			
	Carcinogen (Y/N/Suspect)	N		
Cleaning/ Materials Compatibility	Solubility Parameter			
	Kauri-Butanol value			
	Comp. with Metals			
	Comp. with Elast./Plastics			
	Comp. with Fabrics/Finishes			
	Int. with CW/Decon Agents			
Availability	Commercial (Y/N/Date)	Y	Y	Y
	Samples (Y/N/Date)	Y	Y	Y
	Price ($/lb)			
Potential for Success		Low/Flammable solvent	Med	Med

Solvent Type		Other	Other	Other
Chemical/Product Name		Acrolein	Ethyl Formate	Methyl acetate
		(2-Propenal)		
ASHRAE Designation				
CAS Number		107-02-8	109-94-4	79-20-9
Composition/Formula		C3H4O	HCOOCH2CH3	CH3COOCH3
Manufacturer/Vendor		Several	Several	Several
Environ.	ODP	0	0	0
Acceptability	GWP			
Physical	Molecular weight (daltons)	56	74.09	74
Properties	Boiling Point (F)	126	129.7	134.6
	Heat of Vap. (kcal/kg)		98	
	Vap. Press. (mmHg at 70F)	210	200	171
	Density (g/cm^3)	0.84	0.92	0.93
	Viscosity (cP)			
	Surf. Ten. (dyne/cm)			
Flammability	Flashpoint (F)	-15	-4.3	14
	Firepoint (F)			
	Flam. Lmt/Lower (% vol)	2.8	2.7	3.1
	Flam. Lmt/Upper (% vol)	31	16	16
Toxicity	OSHA/ACGIH PEL (8hr TWA)	0.1 ppm	100 ppm	
	LC50 Inhalation			
	LD50 Skin			
	LD50 Oral			
	Carcinogen (Y/N/Suspect)	N	N	N
Cleaning/	Solubility Parameter			
Materials	Kauri-Butanol value			
Compatibility	Comp. with Metals			
	Comp. with Elast./Plastics			
	Comp. with Fabrics/Finishes			
	Int. with CW/Decon Agents			
Availability	Commercial (Y/N/Date)	Y	Y	Y
	Samples (Y/N/Date)	Y	Y	Y
	Price ($/lb)			
Potential for Success		Low/Flammable solvent	Low/Flammable solvent	Low/Flammable solvent

Solvent Type		Other	Other	Terpene
Chemical/Product Name		N-Methyl-2-pyrrolidone	Tetrahydrofuran	Limonene
		(M-Pyrol)		
ASHRAE Designation				
CAS Number			109-99-9	138-86-3
Composition/Formula		C5H9NO	-CH2CH2CH2CH2O- (cyclic)	C10H16
Manufacturer/Vendor		GAF/ISP	Several	Several
Environ.	ODP	0		0
Acceptability	GWP			
Physical	Molecular weight (daltons)	99	72	136.23
Properties	Boiling Point (F)	395	148-151	175-177
	Heat of Vap. (kcal/kg)	127.3	100.64	
	Vap. Press. (mmHg at 70F)	0.29	133-149	1.4
	Density (g/cm^3)	1.03	0.88	0.84
	Viscosity (cP)	1.65		
	Surf. Ten. (dyne/cm)	40.7		
Flammability	Flashpoint (F)	199	4.7	
	Firepoint (F)			
	Flam. Lmt/Lower (% vol)	2.2	2	
	Flam. Lmt/Upper (% vol)	12.2	11.8	
Toxicity	OSHA/ACGIH PEL (8hr TWA)		200 ppm	Low toxicity
	LC50 Inhalation			
	LD50 Skin			
	LD50 Oral			
	Carcinogen (Y/N/Suspect)	N		N
Cleaning/	Solubility Parameter	11.0		
Materials	Kauri-Butanol value			60
Compatibility	Comp. with Metals	Good		
	Comp. with Elast./Plastics	Poor: ABS, nitrile, PET, PVC, viton		
	Comp. with Fabrics/Finishes			
	Int. with CW/Decon Agents			
Availability	Commercial (Y/N/Date)	Y	Y	Y
	Samples (Y/N/Date)	Y	Y	Y
	Price ($/lb)			
Potential for Success		Low/High boiling point	Low/Flammable compound	Low/High boiling point

Solvent Type		Terpene	Terpene	Terpene
Chemical/Product Name		BBA Solvent K102	Turpentine	Turpentine Blend (TABS D)
ASHRAE Designation				
CAS Number			8006-64-2	
Composition/Formula				
Manufacturer/Vendor		BBA/Union Camp	Several	BBA/Union Camp
Environ. Acceptability	ODP	0	0	0
	GWP			
Physical Properties	Molecular weight (daltons)		136	
	Boiling Point (F)	338-365	302-320	343-365
	Heat of Vap. (kcal/kg)			
	Vap. Press. (mmHg at 70F)		33	<3
	Density (g/cm^3)	0.86	0.86	
	Viscosity (cP)			
	Surf. Ten. (dyne/cm)			
Flammability	Flashpoint (F)	124	95	122
	Firepoint (F)			
	Flam. Lmt/Lower (% vol)		0.8	
	Flam. Lmt/Upper (% vol)			
Toxicity	OSHA/ACGIH PEL (8hr TWA)		100 ppm	
	LC50 Inhalation			
	LD50 Skin			
	LD50 Oral			
	Carcinogen (Y/N/Suspect)	N		
Cleaning/ Materials Compatibility	Solubility Parameter	8.4		
	Kauri-Butanol value	110		67
	Comp. with Metals			
	Comp. with Elast./Plastics			
	Comp. with Fabrics/Finishes			
	Int. with CW/Decon Agents			
Availability	Commercial (Y/N/Date)	Y	Y	Y
	Samples (Y/N/Date)	Y	Y	Y
	Price ($/lb)			
Potential for Success		Low/High boiling point	Low/High boiling point	Low/High boiling point

Solvent Type		Water
Chemical/Product Name		Water
ASHRAE Designation		
CAS Number		7732-18-5
Composition/Formula		H2O
Manufacturer/Vendor		Planet Earth
Environ. Acceptability	ODP	0
	GWP	0
Physical Properties	Molecular weight (daltons)	18
	Boiling Point (F)	212
	Heat of Vap. (kcal/kg)	
	Vap. Press. (mmHg at 70F)	
	Density (g/cm^3)	1
	Viscosity (cP)	
	Surf. Ten. (dyne/cm)	
Flammability	Flashpoint (F)	None
	Firepoint (F)	None
	Flam. Lmt/Lower (% vol)	None
	Flam. Lmt/Upper (% vol)	None
Toxicity	OSHA/ACGIH PEL (8hr TWA)	Non-toxic
	LC50 Inhalation	
	LD50 Skin	
	LD50 Oral	
	Carcinogen (Y/N/Suspect)	N
Cleaning/ Materials Compatibility	Solubility Parameter	
	Kauri-Butanol value	
	Comp. with Metals	Good/Fair
	Comp. with Elast./Plastics	Good
	Comp. with Fabrics/Finishes	Can swell or distort some textiles
	Int. with CW/Decon Agents	
Availability	Commercial (Y/N/Date)	Y
	Samples (Y/N/Date)	Y
	Price ($/lb)	
Potential for Success		Low/High boiling point

INDEX OF SOLVENTS

APPENDIX C

ASHRAE FLUOROCARBON NUMBERING SYSTEM

APPENDIX C

ASHRAE FLUOROCARBON NUMBERING SYSTEM

Numerical codes to designate low molecular-weight fluorocarbons have been used for many years. The American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) devised ASHRAE Standard 34 for methane, ethane, and cycloalkane refrigerants. The coding system has been extended unofficially to include other fluorocompounds.

A. RULES FOR DETERMINING ASHRAE NUMBERS FOR METHANES, ETHANES, AND CYCLOALKANES

1. Each fluorocarbon compound is designated an identifying number which is used in combination with the abbreviation CFC, HCFC, or HFC, depending on the presence of chlorine, fluorine, and/or hydrogen atoms in the compound structure. There are also many trade names used in conjunction with these code numbers, although their use is often reserved for the owners of such trade names or for material specially supplied by such manufacturers.

2. The first digit on the right is the number of fluorine atoms in the compound.

3. The second digit from the right is the number of hydrogen atoms plus one in the compound.

4. The third number from the right is one less than the number of carbons in the compound. When the digit is zero, it is omitted from the number.

5. The number of chlorines is found by subtracting the sum of the fluorine and hydrogen atoms from the total number of atoms which can be connected to carbon atoms.

6. For cyclic derivatives the letter C is sometimes used before the identifying number.

7. In those instances where bromine is present in place of part or all the chlorine, the same rules apply except that the letter B after the designation for the parent chlorofluorocarbon shows the presence of bromine. The number following the letter B shows the number of bromine atoms present.

8. In the case of isomers, each has the same ASHRAE number and the most symmetrical one is indicated by the number without any lower case letter following it. As the isomers become more and more unsymmetrical, the letters a, b, c, etc., are appended. Symmetry is determined by adding the atomic weights of the groups attached to each carbon and subtracting one sum from another. The smaller the difference, the more symmetrical the product.

9. In unsaturated compounds, the number of double bonds is shown by the fourth number from the right.

B. EXTENSION TO PROPANES

1. Propanes

a. Propanes are designated according to the ASHRAE code (l, 1-5), followed by two lower case letters.

b. The first appended letter indicates the substitution on the central (C-2) carbon. The highest total weight of the atoms attached to the central carbon is designated "a," the next highest "b," etc.

c. The second appended letter indicates the substitution at C-1 and C-3 carbons. The relative symmetry is determined by finding the difference of the sum of the atomic weights of the substituents (similar to that described in Section A above). The more unsymmetrical, the higher the letters that are used. Appending letters may be omitted if the code unambiguously corresponds to one and only one possible structure.

Modifications have also been defined to extend these rules to propenes, bromo compounds, compounds of four or more carbons, and fluorothers. For simplicity, these modifications are not described here but are available from ASHRAE.

BIBLIOGRAPHY

Adcock, J.L., S.B. Mathur, W.A. Van Hook, H.Q. Huang, M. Narkhede, and B-H. Wang. *Fluorinated Ethers: A New Series of CFC Substitutes.* Proceedings of the 1991 International CFC and Halon Alternatives Conference, Baltimore, MD. The Alliance for Responsible CFC Policy, Arlington, VA, pp. 386-395 (1991).

Arthur D. Little, Inc. *Comparison of Global Warming Implications of Cleaning Technologies Using a Systems Approach.* Volumes I and II. Report to the Alternative Fluorocarbons Environmental Acceptability Study, August 23, 1991.

Basu, R.S., K.D. Cook, C.C. Li, E.L. Swan. *Stability and Performance of a New Stratospherically Safe Solvent.* SMTCON Technical Proceedings, Surface Mount Technology Conference and Exposition, Atlantic City, NJ. IC Manage, Chicago, IL, pp. 341-345 (1990).

Basu, R.S., and P.B. Logsdon. *Precision Cleaning in Aerospace Industry with HCFC Based Blend - A Status Update.* Proceedings of the 1991 International CFC and Halon Alternatives Conference, Baltimore, MD. The Alliance for Responsible CFC Policy, Arlington, VA, pp. 188-199 (1991).

Beyerlein, A.L., D.D. DesMarteau, S.H. Hwang, N.D. Smith, and P. Joyner. *Physical Property Data on Fluorinated Propanes and Butanes as CFC and HCFC Replacements.* Proceedings of the 1991 International CFC and Halon Alternatives Conference, Baltimore, MD. The Alliance for Responsible CFC Policy, Arlington, VA, pp. 396-405 (1991).

DesMarteau, D.D., A.L. Beyerlein, S.H. Hwang, Y.C. Shen, S.W. Li, R. Mendonca, K.N. Naik, N.D. Smith, and P. Joyner. *Selection and Synthesis of Fluorinated Propanes and Butanes as CFC and HCFC Alternatives.* Proceedings of the 1991 International CFC and Halon Alternatives Conference, Baltimore, MD. The Alliance for Responsible CFC Policy, Washington, DC (1991).

Dev, H., and A. Snelson. *Market Investigation into the Potential Replacements of Trichlorofluoroethane (CFC 113) for the Non-Aqueous Equipment Decontamination System.* Final Report. Contract No. DAAL03-86-D-0001, Delivery Order 2313. U.S. Army Chemical Research, Development, & Engineering Center, Aberdeen Proving Ground, MD, 45 pp. (1991)

Donate, F.A., and J.G. Papajesk. *A New Semi-Aqueous Alternative to 1,1,1-Trichloroethane in Metal Cleaning.* Proceedings of the 1991 International CFC and Halon Alternatives Conference, Baltimore, MD. The Alliance for Responsible CFC Policy, Arlington, VA, pp. 29-39 (1991).

Environmental Protection Agency. 40 CFR Part 82. *Protection of Stratospheric Ozone. Request for Data and Advance Notice of Proposed Rulemaking*. (RIN 2060-AD48) Federal Register, pp. 1984-1990, January 16, 1992.

Environmental Protection Agency. 40 CFR Part 82. *Protection of Stratosphereic Ozone. Notice of Proposed Rulemaking*. Federal Register, pp. 1992-2005, January 16, 1992.

Fabricare Research Center, All Japan Laundry & Dry-Cleaning Association. *Measures for Freon, etc. in Dry-Cleaning Industry in Japan*. Special Seminar for UNEP Solvent Committee in Japan.

Felty, J.R. *Ozone/CFC Cleaning Issues: Alternatives Testing Results*. Proceedings of the 3rd International SAMPE Electronics Conference, Society for the Advancement of Material and Process Eng., Corina, CA, Vol (3), pp. 1011-1022 (1989).

Floden, J.R., and R.E. Tapscott. *Evaluation of Selected Perfluorocarbons as Streaming Agents*. Proceedings of the 1991 International CFC and Halon Alternatives Conference, Baltimore, MD. The Alliance for Responsible CFC Policy, Arlington, VA, pp. 667-676 (1991).

Gallagher, P.M., and V.J. Krukonis. *Precision Parts Cleaning with Supercritical Carbon Dioxide*. Proceedings of the 1991 International CFC and Halon Alternatives Conference, Baltimore, MD. The Alliance for Responsible CFC Policy, Arlington, VA, pp. 262-271 (1991).

Gillum, W.O., and A.M. Jackson. *Replacement of Chlorinated Solvents for In-Line Pre-plate Metal Cleaning with Environmentally Sound Alternatives*. Proceedings of the 1991 International CFC and Halon Alternatives Conference, Baltimore, MD. The Alliance for Responsible CFC Policy, Arlington, VA, pp. 40-48 (1991).

Industry Cooperative for Ozone Layer Protection. *Alternatives for CFC-113 and Methyl Chloroform in Metal Cleaning*. EPA Report EPA/400/1-91/019. U.S. Environmental Protection Agency, Washington, DC, 94 pp. (1991).

Industry Cooperative for Ozone Layer Protection. *Aqueous and Semi-Aqueous Alternatives for CFC-113 and Methyl Chloroform Cleaning of Printed Circuit Board Assemblies*. EPA Report EPA/400/1-91/016. U.S. Environmental Protection Agency, Washington, DC, 88 pp. (1991).

Industry Cooperative for Ozone Layer Protection. *Conservation and Recycling Practices for CFC-113 and Methyl Chloroform*. EPA Report EPA/400/1-91/017. U.S. Environmental Protection Agency, Washington, DC, 78 pp. (1991).

Industry Cooperative for Ozone Layer Protection. *Eliminating CFC-113 and Methyl Chloroform in Precision Cleaning Operations.* EPA Report EPA/400/1-91/018. U.S. Environmental Protection Agency, Washington, DC, 100 pp. (1991).

Kitamura, K., K. Ohnishi, S. Morikawa, and M. Yamabe. *HCFC-225 as a Promising Substitute for Drop-In Replacement of CFC-113.* Proceedings of the 1991 International CFC and Halon Alternatives Conference, Baltimore, MD. The Alliance for Responsible CFC Policy, Arlington, VA, pp. 209-215 (1991).

Logsdon, P.B., and R.S. Basu. *Recovery and Recycle of HCFCs by Activated Carbon Adsorption.* Proceedings of the 1991 International CFC and Halon Alternatives Conference, Baltimore, MD. The Alliance for Responsible CFC Policy, Arlington, VA, pp. 105-113 (1991).

Matsubara, K., Y. Ishii, M. Watanabe and H. Matsuzaki. *CFC Issue in Hitachi.* Hitachi Review, Vol 39(6), pp. 321-328 (1990).

Morrison, P., and K. Wolf. *Substitution Analysis: A Case Study of Solvents.* J. Haz. Materials, Vol 10, pp. 189-204 (1985).

Nimitz, J.S., S.R. Skaggs and J.R. Floden. *Estimation Techniques for Properties of CFC and Halon Alternatives.* Proceedings of the 1990 International CFC and Halon Alternatives Conference, Baltimore, MD. The Alliance for Responsible CFC Policy, Arlington, VA (1990).

Rodgers, J.E. *New Low Ozone Depleting Solvents for Precision Cleaning.* 1989 Proceedings of the Inst. of Env. Sciences 35th Annual Tech. Meeting, Anaheim, CA. Inst. of Env. Sciences, Prospect, IL, pp. 294-295 (1989).

Slinn, D.S. and B.H. Baxter. *Alcohol Cleaning under a Non-Flammable Perfluorocarbon Vapour Blanket.* Proc. of the Tech. Prog. of the Nat. Elect. Pack. and Production Conf., NEPCON West 90. Cahners Publishers, Vol (2), pp. 1810-1819 (1990)

Tadros, M., T. Shah, C. Matzdorf, and J. Hayes. *A New Semi-Aqueous Cleaning Material for Electronics Defluxing.* Proc. of the Tech. Prog. of the Nat. Elect. Pack. and Production Conf., NEPCON East 90. Cahners Publishers, pp. 151-160 (1990).

Tapscott, R.E., T.A. Moore, and J.P. Moore. *A Database of Halocarbon Candidates for Halon and CFC Alternatives.* Proceedings of the 1989 International CFC and Halon Alternatives Conference, Washington, DC. The Alliance for Responsible CFC Policy, Arlington, VA (1989).

Textile Services Association, Ltd. *Safety in Dry Cleaning.* North Harrow, Middlesex, Great Britain, 1990.

Yellow, J. *Compatibility Testing Procedures and Results for Plastics and Elastomers Used with Alternative Cleaning Agents.* 1990 Proc. of the 40th Electronic Components and Tech. Conference, IEEE, Vol (1), pp. 258-260 (1990).

GLOSSARY

Aerosol spray
A means of atomizing liquids by propelling them from a pressurized container through a suitable valve by either a liquefied or pressurized gas.

Alcohols
A series of hydrocarbon derivatives with at least one hydrogen atom replaced by an -OH group. The simplest alcohols (methanol, ethanol, n-propanol, and isopropanol) are good solvents for some organic soils, but are flammable and can form explosive mixtures with air.

Aqueous cleaning
Cleaning with water to which suitable detergents, saponifiers, or other additives may be added.

Azeotrope
A mixture of chemicals is an azeotrope if the vapor composition is identical to that of the liquid phase. This means that the distillate of an azeotrope is theoretically identical to the solvents from which it is distilled. In practice, the presence of contaminants in the solvent may upset the azeotrope.

Biodegradable
Products are classified as biodegradable if they can be easily broken down or digested by living organisms.

Chlorocarbon
An organic substance composed of chlorine and carbon, e.g., carbon tetrachloride.

Chlorofluorocarbon (CFC)
An organic substance composed of chlorine, fluorine, and carbon atoms, usually characterized by high stability contributing to a high ozone depletion potential.

Controlled atmosphere soldering
A soldering process done in a relatively oxygen-free atmosphere. The process greatly reduces oxidation of the solder, so that less flux is required, thereby reducing or eliminating the need for cleaning.

Defluxing
The removal of flux residues after a soldering operation. Defluxing is a part of most high reliability electronics production.

Detergent

A product designed to render soils (e.g., oils and greases) soluble in water, usually made from synthetic surfactants.

Drycleaning

A common term for cleaning textiles and garments in organic solvents as opposed to water.

Fatty acids

The principal part of many vegetable and animal oils and greases. Also known as carboxylic acids, which embrace a wider definition. These are common contaminants which use solvents for their removal. They are also used to activate fluxes.

Flux

A chemical employed in the soldering process to facilitate the production of a solder joint. It is usually a liquid or solid material, frequently based on rosin (colophony).

Global warming potential (GWP)

A unit of measurement developed by the Intergovernmental Panel on Climate Change (IPCC) to estimate relative contributions of various greenhouse gases to global warming. GWP is defined as the time-integrated commitment to global warming of the instantaneous release of 1 kg of gas relative to 1 kg of CO_2. GWP is determined by the ability of the compound to absorb infrared radiation, the compound's atmospheric lifetime, and the time period over which the compound is compared with CO_2. GWP values for integration time horizons of 20, 100, and 500 years have been determined. Similar to ODP, GWP values are often reported relative to a scale that sets the GWP of CFC-11 equal to 1.0.

Greenhouse effect

A thermodynamic effect whereby energy absorbed at the earth's surface and normally radiated back out to space in the form of long-wave infrared radiation, is retained due to gases in the atmosphere, causing a rise in global temperature. CFCs that cause ozone depletion are believed to contribute to the greenhouse effect, with a single CFC-113 molecule having the same estimated global warming effect as 14,000 carbon dioxide molecules.

Halocarbon

An organic compound where at least one hydrogen atom in the hydrocarbon molecule has been replaced by a halogen atom (fluorine, chlorine, bromine, iodine, or astatine).

Halons

Substances used as fire-extinguishing agents which generally are relatively low molecular weight halocarbon compounds, usually including a bromine atom for superior chemical extinguishment. Several halons (Halon-1211, Halon-1301, and Halon-2402) have been targetted for phaseout due to their high ozone-depletion potential.

Hydrocarbon

An organic substance composed only of hydrogen and carbon. Gaseous or volatilized hydrocarbons are flammable.

Hydrocarbon/surfactant solvents

A mixture of low-volatility hydrocarbon solvents with surfactants, allowing the use of a two-phase cleaning process. The first phase is solvent cleaning in the blend and the second phase is water washing and rinsing to remove the residues of the blend and any other water-soluble soils. The surfactant ensures the water-solubility of the otherwise insoluble hydrocarbon. Also referred to as semi-aqueous solvents.

Hydrochlorocarbon

An organic substance composed of hydrogen, chlorine, and carbon, e.g., trichloroethylene.

Hydrochlorofluorocarbon (HCFC)

An organic substance composed of hydrogen, chlorine, fluorine, and carbon atoms. These chemicals are less stable than CFCs, thereby having generally lower ozone depletion potentials.

Hydrofluorocarbon (HFC)

An organic substance composed of hydrogen, fluorine, and carbon atoms. These chemicals are not, at present, believed to be ozone-depleting compounds although they do have high global warming potentials.

Isomer

Compounds that have the same molecular formula (i.e., same types and numbers of atoms) but have different structures are defined as structural isomers or isomers. The number of isomers for a given molecular formula increases as the number of atoms increases. See Appendix C for further information on the ASHRAE system for numbering halocarbon compounds and their various isomers.

Low-solids flux

A flux which contains little solid matter, thereby reducing or eliminating the need for cleaning. See no-clean flux.

Metal cleaning

General cleaning or degreasing of metallic surfaces or assemblies generally with unspecified cleanliness requirements.

No-clean flux

A flux whose residues do not have to be removed from an electronics assembly; therefore, no cleaning is necessary. This type of flux is often characterized by low quantities of residues.

Ozone

A gas formed when oxygen is ionized. Ozone partially filters certain wavelengths of UV light from the earth. Ozone is a desirable gas in the stratosphere, but can be toxic to living organisms at ground level.

Ozone depletion

Accelerated chemical destruction of the stratospheric ozone layer. Ozone depletion is believed to be accelerated by chlorine and bromine free radicals liberated from relatively stable chlorinated, fluorinated, and brominated products by ultraviolet radiation in the ozone layer.

Ozone-depletion potential

A relative index of the ability of a substance to cause ozone depletion with the reference level of 1 is assigned to CFC-11 and CFC-12. For example, if a product has an ozone-depletion potential of 0.5, a given weight of the product in the atmosphere would, in time, deplete half the ozone that the same weight of CFC-11 or CFC-12 would deplete. Ozone-depletion potentials are calculated from mathematical models which take into account factors such as the stability of the product, the rate of diffusion, the quantity of depleting atoms per molecule, and the effect of ultraviolet light and other radiation on the molecules.

Ozone layer

A layer in the stratosphere, at an altitude of approximately 10-50 km, where a relatively high concentration of ozone filters harmful ultraviolet radiation from the earth.

Perfluorocarbon

An organic substance composed of fluorine and carbon, in which all of the parent hydrogen atoms in a hydrocarbon are replaced with fluorine atoms

Perhalogenation

An organic molecule is perhalogenated if all of the parent hydrogen atoms in a hydrocarbon are replaced with halogen atoms (astatine, bromine, chlorine, fluorine, or iodine). For example, carbon tetrachloride (CCl_4) is perchlorinated methane (CH_4) and perfluorohexane (C_6F_{14}) is perfluorinated hexane (C_6H_{14}).

Precision cleaning
Cleaning of high-precision mechanical parts and electronic sensory devices, as opposed to general metal cleaning. This is usually done in "cleanrooms," with low particulate contamination, to specific standards.

Printed circuit
A printed circuit is a component for interconnecting other components. It usually consists of a metallic conductor pattern on an organic insulating substrate. After fabrication, it is known as a printed circuit board (PCB); after assembly with components it is sometimes referred to as a printed wiring assembly (PWA).

Saponifier
A chemical designed to react with organic fatty acids, such as rosin, some oils and greases, etc., to form water-soluble soaps. This is a method for defluxing and degreasing. Saponifiers are usually alkaline and may be mineral based (sodium hydroxide or potassium hydroxide) or organic based (water solutions or monoethanolamine).

Semi-aqueous solvents
Another name for hydrocarbon/surfactant (HCS) solvents. Hydrocarbon/surfactant (HCS) solvent is preferred as the more descriptive and accurate name although the term semi-aqueous cleaner is often used in product information to describe such cleaners. Semi-aqueous cleaning processes generally involve two stages, a cleaning stage followed by a water rinsing stage to remove solvent and soil residues. General types of solvents used in semi-aqueous cleaning processes include glycol ethers, esters, pyrollidone, hydrocarbons, and terpenes.

Solvent containment
Means of reducing the emission of solvents (e.g., CFCS) into the environment. This technique usually involves improving the design and operation of the equipment in which the solvent is used.

Surfactant
A chemical to reduce the surface tension of water. Also referred to as surface-active agents. Detergents are made primarily from surfactants.

Terpene
Class of homocyclic hydrocarbons with the empirical formula $C_{10}H_{16}$. Turpentine is mainly a mixture of terpenes. See also hydrocarbon/surfactant solvents.

Ultrasonic cleaning
Immersion cleaning where mechanical energy formed by cavitational implosions close to the surfaces being cleaned significantly aids the cleaning operation.

Vapor-phase cleaning

A cleaning process, usually with CFC-113 solvent or hydrochlorocarbon solvents, where the final rinse is achieved by condensing solvent vapors on the parts being cleaned.

Volatile organic compound (VOC)

Organic compounds that evaporate at ambient temperature or their temperature of use. In some legislation this definition is further narrowed to include only those compounds which, by a photochemical reaction under certain climatic conditions, will cause atmospheric oxygen to be converted into potentially smog-promoting tropospheric ozone.

Water-soluble flux

A flux whose post-soldering residues may be removed by a water wash. Such fluxes are usually very active, so adequate defluxing is an essential part of their use. They are also known as Organic Acid (OA) fluxes or inorganic acid fluxes.